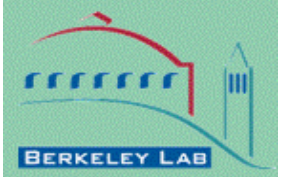


ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Calendar Year 2008 Program Benefits for ENERGY STAR Labeled Products

Gregory K. Homan, Marla Sanchez, Richard E. Brown, and Judy Lai

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
University of California
Berkeley, California 94720

August 24, 2010

This work was supported by the U.S. Environmental Protection Agency, Climate Protection Partnerships Division, Office of Air and Radiation, under Department of Energy contract No. DE-AC02-05CH11231.

Disclaimer

Calendar Year 2008 Program Benefits for ENERGY STAR Labeled Products

Gregory K. Homan, Marla Sanchez, Richard E. Brown, and Judy Lai

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
University of California
Berkeley, California 94720

August 24, 2010

DISCLAIMER

Acknowledgments

This work was supported by the U.S. Environmental Protection Agency, Climate Protection Partnerships Division, Office of Air and Radiation, under Department of Energy contract No. DE AC03 76SF00098. Several EPA staff have contributed to these forecasts over the years: Ann Bailey, Peter Banwell, Glenn Chinery, Andrew Fanara, Craig Hershberg, Katharine Kaplan, Ashley King, Linda Latham, Steve Ryan, Rachel Schmeltz, Robin Shudak, Stephan Sylvan, Jeremy Symons. Ed Barbour (Navigant Consulting), Bill McNary (D&R International), Robin Clark (ICF Consulting), Darcy Martinez Clark (ICF Consulting), Rebecca Duff (ICF Consulting) Carrie Webber (LBNL) and Sarah Bretz (LBNL) also contributed to the analysis. We acknowledge Dr. Jim McMahon (LBNL) for reviewing previous versions and for providing valuable feedback and Alan Meier (LBNL) for reviewing this report.

Contents

Figures and Tables

Executive Summary

ENERGY STAR is a voluntary energy efficiency labeling program operated jointly by the Environmental Protection Agency (US EPA) and the U.S. Department of Energy (US DOE), designed to identify and promote energy-efficient products, buildings and practices. Since the program inception in 1992, ENERGY STAR has become a leading international brand for energy efficient products, and currently labels more than thirty products, spanning office equipment, heating, cooling and ventilation equipment, commercial and residential lighting, home electronics, and major appliances. ENERGY STAR's central role in the development of regional, national and international energy programs necessitates an open process whereby its program achievements to date as well as projected future savings are shared with stakeholders. This report presents savings estimates for ENERGY STAR labeled products. We present estimates of energy, dollar, and carbon savings achieved by the program in the year 2008, annual forecasts for 2009 and 2010, and cumulative savings estimates for the period 1993 through 2008 and cumulative forecasts for the period 2009 through 2015. Through 2008 the program saved 8.8 Quads of primary energy and avoided the equivalent of 158 metric tones carbon (MtC). The forecast for the period 2009-2015 is 18.1 Quads or primary energy saved and 316 MtC emissions avoided. The sensitivity analysis bounds the best estimate of carbon avoided between 104 MtC and 213 MtC (1993 to 2008) and between 206 MtC and 444 MtC (2009 to 2015).

1. Introduction

This paper presents current and projected savings for ENERGY STAR labeled products, and details the status of the model as implemented in the September 2009 spreadsheets.

ENERGY STAR is a voluntary labeling program operated jointly by the US Environmental Protection Agency (US EPA) and US Department of Energy (US DOE). These agencies enter into partnership agreements with manufacturers and key stakeholders to promote products that meet certain energy-efficiency and performance criteria established by the agencies. By encouraging the adoption of high efficiency products and contributing to transformation of markets DOE and EPA reduce air pollution and greenhouse gases associated with the consumption of energy. Since its inception in 1992, the ENERGY STAR label has been used to promote high efficiency office equipment, heating and cooling equipment, appliances, lighting, windows, transformers, buildings, and commercial kitchen equipment, among other product areas. For a more detailed description of the ENERGY STAR program, refer to McWhinney et al. (2005) and Brown et al. (2002). In this report we address the following questions for ENERGY STAR labeled products:

- How are ENERGY STAR impacts quantified?
- What are the ENERGY STAR achievements?
- What are the limitations to our method?

2. Study Scope

ENERGY STAR consists of four programmatic areas: products, buildings (including industrial plants), home performance, and new homes. Complete descriptions of these program areas can be found at www.energystar.gov. This report focuses only on labeled products such as office equipment, appliances, and electronics, and does not cover savings for buildings and industrial plants, new homes, or home performance. The methodologies for quantifying savings for these program segments are significantly different than the methodology for EPA labeled products. We cannot address these additional methodologies and results with the necessary detail within the scope of this report. See Horowitz (2001, 2004, 2007) for a complete summary of program impacts for ENERGY STAR Buildings. See US EPA (2006) for a summary of program impacts for ENERGY STAR home performance, industrial plants, and new homes.

ENERGY STAR product types are shown in **Table 1**. For each product type, we list the program start year and the dates for subsequent specification revisions. The full eligibility requirements for each product can be found at www.energystar.gov.

Table 1. Summary of ENERGY STAR product specifications

Specification Effective Dates	Initial	Revisions
Product types included in analysis		
Audio and DVD1,2	1999	2003, 2009
Battery charging systems	2006	
Boilers	1996	2002
CAC/ASHP2	1995	2002, 2006, 2009
Ceiling fans	2002	2003, 2006
CFL	1999	2001, 2004, 2008
Commercial dishwasher	2007	
Commercial fryers	2003	
Commercial Griddles	2009	2011
Commercial hot food holding cabinets	2003	
Commercial Ovens	2009	
Commercial solid door refrigerators and freezers	2001	2009
Commercial steam cookers	2003	
Computers	1992	1995, 1999, 2000, 2007, 2009
Copiers	1995	1997, 1999, 2007, 2009
Decorative light strands	2008	
Dehumidifiers	2001	2006, 2007, 2008
Digital TV Adapters	2007	
Displays	1992	1995, 1998, 1999, 2005, 2006
Exit signs3	1996	1999, 2004
External power adapters	2005	
Facsimile	1995	
Furnaces	1995	2006, 2009
Geothermal HP2	1995	2001
Ice machines	2008	
Light commercial HVAC2	2002	2004
Multifunction devices	1997	1999, 2007, 2009
Printers	1993	1995, 2000, 2001, 2007, 2009 (proposed)
Programmable thermostats3	1995	2008
Professional Displays	2009	
Refrigerators and freezers	1996	2001, 2003, 2004, 2008
Residential clothes washers	1997	2001, 2004, 2007, 2009, 2011
Residential dishwashers	1996	2001, 2007
Residential light fixtures	1997	2001, 2002, 2003, 2005, 2008
Roof products	1999	2005, 2007
Room air cleaners	2004	
Room air conditioners	1996	2000, 2003, 2005
Scanners	1997	2007, 2009
Servers	2009	
Set-top boxes3	2001	*2005, 2009
Telephony	2002	2004, 2006, 2008
Televisions/VCRs2	1998	2002, 2004, 2005, 2008
Traffic signals3	2000	2003, *2007
Transformers3	1995	*2007
Vending machines	2004	2006, 2007
Ventilation fans	2001	2003
Water coolers	2004	2004
Product types not included in analysis		
Buildings and industrial plants	1991	1995, 1999, 2000, 2001, 2002, 2004, 2006
Home performance	2000	2002
Insulation	1995	*2002
New homes	1995	1997, 2006
Windows, doors, and skylight	1997	2003, 2005, 2009

Notes to Table 1:

1) Audio includes CDs, mini-systems, audio separates, and home theater in a box.

2) CAC =central air conditioning, ASHP = air source heat pump, HP = heat pump, DVD = digital versatile disc, CFL = compact fluorescent lamp, HVAC = heating ventilation and air conditioning, VCR=video cassette recorder.

3) Specification revisions that resulted in program suspension are indicated with an "*". The Set-top box specification was suspended in 2004 and then re-launched in 2009.

4) Buildings and Industrial Plants, New Homes, and Home Performance programs are administered by EPA but are not included due to a different program benefits methodology.

5) Changes to ENERGY STAR buildings and industrial plants reflect building types or manufacturing sectors added to the program.

6) Insulation specification revised in 2002 and insulation incorporated into Home Performance with ENERGY STAR.

Our study tracks carbon savings, energy savings, monetary savings, net monetary savings (monetary savings minus the incremental investment cost of realized savings), and peak power reductions for the analysis period 1993-2025. Our model tracks these indicators on an annual basis and also generates cumulative results over several time periods. In this report, we present annual results for energy savings, peak load savings, carbon savings and monetary savings for calendar year 2008, and forecasts for 2009, and 2010. We present cumulative results for energy savings, carbon savings, and monetary savings over the period 1993-2008. Although the model results extend through 2025, we present cumulative forecasts for energy savings, carbon savings, and monetary savings over the period 2009-2015 to minimize the uncertainty inherent in an extended forecast.

3. Program Attribution

Numerous supporting stakeholders including utilities, regional energy partnerships, energy consortiums, and non-profit organizations leverage the ENERGY STAR program nationally. All stakeholders work towards advancing ENERGY STAR goals, improving ENERGY STAR consumer awareness, and promoting the sales of ENERGY STAR products. This report provides estimates are forecasts of national savings achieved by ENERGY STAR voluntary product labeling summarized at a high level but does not make an attempt to attribute the national savings across federal, regional, state and/or local efforts.

4. Technical Approach

4.1 Overview

We employ a bottom-up methodology for quantifying savings for ENERGY STAR labeled products. Each ENERGY STAR product type is characterized by product-specific inputs that result in a product savings estimate. ENERGY STAR program impacts are the sum of the impacts for each individual ENERGY STAR product type. The bottom-up model allows us to separately evaluate the implementation process for each product type and quantify ENERGY STAR's impact within each market. In addition, ENERGY STAR specifications are often a key component of many regional energy efficiency efforts, and the bottom-up model allows ENERGY STAR to distribute product data that can facilitate the development of localized programs.

We implement the bottom-up model with awareness that uncertainty for each product type contributes to uncertainty in total ENERGY STAR impacts. This means that many small inaccuracies are additive overall and any one inaccuracy for a product type with large energy savings can significantly affect the overall results. To address uncertainty, we run sensitivity tests on key variables including ENERGY STAR unit sales, energy prices and carbon emission factors[1]. While all input data are regularly updated, we put extra effort into updating the inputs for the office equipment product category because of the large energy savings potential, as well as consumer electronics where usage patterns are more uncertain and new field data are becoming increasingly available (Porter et al. 2006; Nordman and McMahon, 2004; Roth and McKenny, 2007).

Where other organizations have collected market or engineering data pertaining to ENERGY STAR product types, we integrate that data into our inputs as applicable. We also work with the US DOE's Energy Information Administration (US EIA) to harmonize inputs into our model with the National Energy Modeling System (NEMS), which is used to generate national energy forecasts at both the sector and end-use level. We also share with other organization our data on product power consumption, usage, total energy, and ENERGY STAR market shares for product types that are individually treated in both

[1] The sensitivity analysis is in section 5.2 and includes varying carbon inputs. We do not present monetary or energy results for price and heat rate sensitivity.

models, including residential heating and cooling equipment, televisions and set-top boxes, home computers, commercial office equipment, and lighting.

4.2 Methodology Summary

We begin the analysis by segmenting sales of each product type into non-ENERGY STAR and ENERGY STAR units. Manufacturer and retail partners report ENERGY STAR unit sales to the respective program agencies[2] each calendar year[3]. The labeled products for which partners reported ENERGY STAR sales in 2008 are listed in T**able 2**.

Table 2. EPA Energy Star Products with Partner Reported Shipment Data

• Audio/DVD Products	• Battery Charging Systems
• Boilers	• Ceiling Fans
• Central Air Conditioners and Air-Source Heat Pumps	• Commercial Dishwashers
• Commercial Fryers	• Commercial Hot Food Holding Cabinets
• Commercial Ice Machines	• Commercial Refrigerators and Freezers
• Commercial Steam Cookers	• Computers
• Decorative Light Strings	• Decorative Light Strings (DLS)
• Dehumidifiers	• Digital-to-Analog Converters (DTAs)
• External Power Supplies	• External Power Supplies and End-Use Products with Qualified EPS
• Furnaces	• Geothermal Heat Pumps
• Imaging Equipment	• Light Commercial HVAC
• Monitors	• Residential Light Fixtures (RLF)
• Roof Products	• Room Air Cleaners
• Telephony	• TVs/VCRs
• Vending Machines	• Ventilating Fans
• Water Coolers	

Source: ICF, 2009

Unit sales for EPA labeled products not reported by partners are LBNL estimates based on market research reports and industry estimates.

Non-ENERGY STAR unit sales are estimated as the difference between total US unit sales obtained from industry reports and ENERGY STAR unit sales. **Table 3** shows actual ENERGY unit sales for 2008 and projected ENERGY STAR unit sales for 2009.

Table 3. ENERGY STAR Market Shares for 2008 and projections for 2009

	Actual 2008			Projected 2009		
Equipment Type	Total Energy Star Shipments	Total US Shipments	Energy Star Market Share	Total Energy Star Shipments	Total US Shipments	Energy Star Market Share
	1000s	1000s		1000s	1000s	
Office Equipment						
-Office Copiers	140	153	91%	95	104	91%
-Office Facsimile	37	974	4%	44	945	5%
-Office Printers	2,109	4,920	43%	2,531	3,447	73%
-Office Scanners	180	207	87%	146	146	100%
-Office Multi-function	8,411	17,317	49%	9,253	16,678	55%
-Office CRTs	25	97	26%	4	13	30%
-Office LCD	18,697	22,236	84%	15,232	18,116	84%
-Office PCs	9,890	40,131	25%	10,388	35,082	30%
-Servers	0	2,475	0%	390	1,950	20%
-Professional Displays PDP	0	488	0%	0	614	0%
-Professional Displays LCD	0	767	0%	0	1,549	0%
Residential Office Equipment						
-Residential Copiers	0	0	-	0	0	-
-Residential Facsimile	107	2,840	4%	129	2,755	5%

[2] Through 2008 labeled products were divided between US EPA and DOE. Starting in 2009 EPA will track all Energy Star labeled products.

[3] ENERGY STAR unit sales data have been collected from manufacturer partners as part of the ENERGY STAR Program requirements for calendar years 2002-2008 (ICF 2003, 2004, 2006a, 2006b, 2007, 2008. 2009). ENERGY STAR sales data for earlier years and subsequent forecast years are based from industry and market data. The DOE Labeled product dishwashers, clothes washers, room A/C and CFLs have sales data complied by D&R International, and are available from Energy Star. Starting in 2009 EPA will

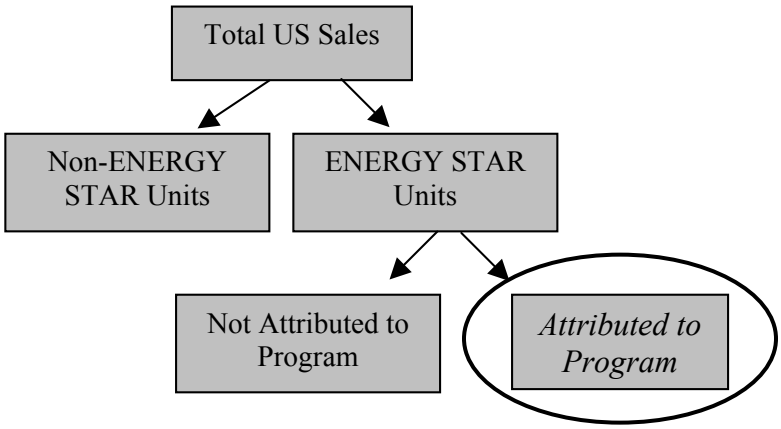
-Residential Printers	1,670	3,896	43%	2,004	2,745	73%
-Residential Scanners	323	373	87%	262	262	100%
-Residential Multi-function	1,244	2,562	49%	1,369	2,536	54%
-Residential CRTs	12	45	26%	0	7	7%
-Residential LCD	8,777	10,438	84%	7,626	9,070	84%
-Residential PCs	10,069	54,724	18%	10,320	68,178	15%
Consumer Electronics						
-Digital Picture Frames	0	7,419	0%	0	9,868	0%
-TVs	25,786	32,670	79%	25,205	33,840	74%
-VCRs	0	988	0%	0	460	0%
-TV/VCR/DVD	1,128	1,680	67%	1,122	1,671	67%
-DVD Player	10,046	22,781	44%	10,549	22,855	46%
-Mini-Systems	96	3,951	2%	101	3,793	3%
-Home Theater	729	3,966	18%	767	4,150	18%
-Audio Separates	419	2,003	21%	420	2,048	20%
-Compact Disc Player	174	217	81%	141	175	81%
-Answering Machines	0	897	0%	0	889	0%
-Cordless Phones	4,824	11,532	42%	4,799	11,474	42%
-DSS Cordless Phones	1,724	4,121	42%	1,224	4,080	30%
-Combination Phones	4,373	7,487	58%	4,352	7,561	58%
-DSS Combination Phones	6,278	10,746	58%	4,255	10,639	40%
-Additional Handsets	365	949	39%	362	940	39%
-DTA	13,018	19,767	66%	9,763	14,825	66%
-Set-top Box	0	23,429	0%	5,680	23,572	24%
-External Power Supplies	266,316	565,704	47%	65,121	622,001	10%
-Battery charger	6,225	41,668	15%	6,319	42,085	15%
Heating and Cooling						
-Air Source Heat Pump	410	1,865	21%	416	1,885	21%
-Geothermal Heat Pump	75	130	4%	77	133	4%
-Central Air Conditioner	740	3,968	19%	563	4,008	14%
-Gas Furnace	988	2,300	43%	1,003	2,337	43%
-Oil Furnace	7	59	12%	7	59	12%
-Gas Boiler	110	192	57%	111	192	58%
-Oil Boiler	75	122	62%	76	122	63%
-Unitary HVAC	224	750	30%	240	759	32%
-Thermostats	2,549	6,610	39%	2,668	6,682	40%
Lighting						
-Indoor Fixtures	16,276	165,648	10%	20,774	167,305	12%
-Outdoor Fixtures	5,432	28,905	19%	5,574	29,194	19%
-Exit Signs	0	4,067	0%	0	4,115	0%
-CFL	266,439	1,229,974	22%	282,426	1,163,817	24%
-Decorative Light Strands	11,715	126,187	9%	21,497	128,080	17%
-Traffic Signal	0	8,840	0%	0	8,840	0%
Residential Appliances						
-Clothes Washers	2,902	8,292	35%	2,952	8,434	35%
-Dishwashers	5,018	5,903	85%	5,071	5,966	85%
-Refrigerators	1,862	9,310	20%	2,116	9,403	23%
-RAC	4,997	9,086	55%	5,047	9,176	55%
-Dehumidifiers	1,173	1,572	75%	1,200	1,598	75%
-Air Cleaners	390	2,567	15%	421	2,631	16%
-Exhaust Fans	696	6,432	11%	743	6,511	11%
-Ceiling Fans Only	2,500	7,760	32%	2,960	7,812	38%
-Ceiling Fan with Light Kit	127	10,045	1%	139	10,121	1%
-Light Kit for Ceiling Fan	45	2,167	2%	50	2,183	2%
Commercial Appliances						
-Vending Machines	78	246	32%	80	246	32%
-Hot Food Holding Cabinet	24	30	79%	23	30	79%
-Steamers	5	23	23%	5	22	24%
-Fryers	7	90	7%	7	91	7%
-Commercial Refrigeration	193	292	66%	195	292	67%
-Water Coolers	516	1,264	41%	522	1,328	39%
-Ice Machines	55	138	40%	57	142	40%
-Dishwashers	24	28	83%	24	29	83%
-Ovens	0	219	0%	64	221	29%
-Griddles	0	15	0%	5	15	33%
Other						
-Utility Transformers	0	1,436	0%	0	1,465	0%

-C&I Transformers	0	274	0%	0	277	0%
-Residential Roofing (1000 sq ft)	0	5	11%	0	5	11%
-Commercial Roofing (1000 sq ft)	3	16	19%	3	16	20%

Notes to Table 3:
1) Columns may not equal due to rounding
2) 2008 ENERGY STAR units are from ICF (2009) with the exception of the following products: residential and office copiers, fax, printers, scanners, MFDs, and PCs are extrapolated from Gartner (2001). Residential clothes washers, dishwashers, RAC, and refrigerators are from email communication with D&R International. Thermostat market shares are an industry estimate provided by Honeywell
3) ENERGY STAR exit signs, traffic signals, and transformers are discontinued. (program savings continue to accrue due to existing stock)
4) Residential PCs include desktops, laptops, and video games
5) Office PCs include desktops, laptops, and workstations
6) Unitary HVAC is expressed in million square feet
7) Roofing is expressed in billion square feet
8) PC market shares in 2008 reflect the revised computer specification
9) Projected 2009 market shares are LBNL best estimates taking into consideration past ENERGY STAR unit sales, new product launches, ENERGY STAR specification revisions, and trends in total US sales

Having segmented total shipments into ENERGY STAR and non, the units meeting the ENERGY STAR criteria are further divided into those that would have been sold even without the program and those that can be attributed to the program. The estimated sales of ENERGY STAR units not due to the program are a forecast based on our market share analysis of models that met the ENERGY STAR specification prior to implementation of the program for each product type. This analysis is based on energy consumption test results for individual product models that are submitted by manufacturers to EPA and DOE during the ENERGY STAR product development phase. We analyze the test data according to the applicable ENERGY STAR performance metric and calculate the business as usual (BAU) penetration rate as the total number of models in the dataset divided by the number of models that meet ENERGY STAR requirements. ENERGY STAR savings include only the savings for ENERGY STAR units directly attributable to the program. Figure 1 illustrates the sales segmentation.

Figure 1. Market segmentation of ENERGY STAR products



We next estimate unit energy consumptions (UEC) for both non-ENERGY STAR and ENERGY STAR units. Our BAU forecast is comprised of standard efficiency unit sales (representing units that do not meet the ENERGY STAR requirement) and high efficiency non-ENERGY STAR unit sales (representing units that meet or exceed ENERGY STAR requirement but are not attributable to the program). The BAU is characterized both by a UEC and a market share for each segment. BAU efficiency improvements can be modeled directly as a change in the UEC of either of these segments. We can also model BAU efficiency improvements as a shift over time from standard efficiency units to high efficiency non-ENERGY STAR units.

The method used to calculate the UEC for each product falls into one of three general categories: mode-based, duty cycle and exogenous annual UEC based. Mode based products have multiple operational

modes. The most common operational modes are active, idle, sleep or off. Each mode is characterized by a power level and a usage pattern, i.e. the amount of time the device spends in that mode. Total annual energy is the summation of the annual modal energy consumptions. Duty-cycle products typically do not have differentiated operational modes and their annual energy consumption is calculated from detailed power and usage inputs. Exogenous annual UEC products are those whose annual consumption is a single value (with no details on product power and usage) taken from a source outside the model (e.g. third party metering, other research). **Table 4** summarizes the UEC calculation method for the included products.

Table 4. Summary of UEC Methodology by Product

Program	Product	Electronic Modal	Duty Cycle	Exogenous Annual UEC
Office Equipment	Computers	**X**		**X**
	Servers	**X**		
	Displays	**X**		
	Imaging (Inkjet or Laser: printer fax, scanner, copier, MFD)	**X**		**X**
	Professional Displays	**X**		
Consumer Electronics	Digital Picture Frames	**X**		
	TVs	**X**		
	VCRs	**X**		
	TV/VCR/DVD	**X**		
	DVD Player	**X**		
	Audio Equipment (audio separates)			**X**
	Audio Equipment (mini-system, HTIB, CD)	**X**		
	Telephony	**X**		
	Digital TV Adapter	**X**		
	Set-top Box (cable, satellite, IP)			**X**
	External Power Supplies	**X**		**X**
	Battery Charging Systems	**X**		**X**
Heating & Cooling	Furnace, Boiler, CAC, AS & GeoHP, lt. Com. HVAC, Thermostat			**X**
Lighting	Fixtures, Exit sign, DLS, Traffic signal, CFL		**X**	
Residential Appliances	Room Air Conditioners		**X**	
	Dehumidifiers		**X**	
	Air Cleaners		**X**	
	Exhaust Fans			**X**
	Ceiling Fans			**X**
	Dishwashers		**X**	
	Refrigerators		**X**	
	Clothes Washers		**X**	
Commercial Appliances	Water Coolers			**X**
	Commercial Refrigeration (refrigerators, freezers)			**X**
	Hot Food Holding Cabinets		**X**	
	Fryers		**X**	
	Steamers		**X**	
	Ice Machines		**X**	
	Dishwashers		**X**	
	Vending Machines		**X**	
	Griddles		**X**	
	Ovens		**X**	
Other	C&I, Utility Transformers		**X**	
	Residential and Commercial Roofing			**X**

Notes to table 4:
1) External power supply and battery charger are categorized as electronic modal, duty-cycle, or exogenous annual UEC, depending on what equipment attaches to them.
2) Inkjet technology is electronic modal-based, and laser technology is exogenous annual UEC-based.
3) Roofing savings are based on a given UES.
4) Set-top box cable and satellite used an electronic modal calculation from 2001 through 2005 when the program was suspended. The specification was revised in 2009, at which point the calculation became exogenous annual UEC-based. DTA is electronic modal-based.

The unit energy savings (UES) for each product type is the difference between the BAU UEC and the ENERGY STAR UEC in a given year. The UES for most product types changes over time due to specification revisions, usage pattern changes, and changes to the BAU efficiency. To account for this variation, we calculate the energy savings for each year's ENERGY STAR sales and then use a retirement function to add up the savings for all the equipment vintages in place in a given year. We assume that

ENERGY STAR units remain in service and accrue savings for a period equal to the average product lifetime.

Aggregate energy bill savings are estimated using year-by-year energy prices from DOE shown in **Table 5**. Energy bill savings are discounted at a 4 percent real discount rate. Carbon emissions reductions are calculated from energy savings using fuel specific carbon emissions factors. Carbon emission reductions for electricity are estimated using EPA's national average marginal carbon factor, which is derived from models used as part of the US government's reporting requirements under the U.N. Framework Convention on Climate Change and historical emissions data from US EPA's Emissions and Generation Resource Integrated Database (eGRID). Forecast marginal carbon factors for electricity are derived from energy efficiency scenario runs of the integrated utility dispatch model (IPM®) (US EPA 2007). Carbon emission factors for natural gas and oil are assumed to be constant throughout the period at 14.4 kg C/MBtu for natural gas and 19.75 kg C/MBtu for oil. Heat rates are average rates and not marginal.

Table 5. Best estimate energy prices and carbon factors by year (2008 dollars)

Year	Cmcl. Elec Price	Res. Elec Price	Cmcl. Gas Price	Res. Gas Price	Oil Price	Price Sources	Elec. Carbon Emission Factor	Electric Heat Rate	Electric Heat Rate Sources
	$/kWh[2]	$/kWh[2]	$/MBtu	$/MBtu	$/MBtu	US DOE [3]	MMTC/ TWh[1,4]	Btu/kWh	US DOE [3]
1993	0.108	0.115	6.931	8.233	9.074	1996a	0.203	11,019	1996a
1994	0.107	0.115	7.257	8.493	8.626	1996b	0.203	10,948	1996b
1995	0.099	0.111	6.613	7.918	8.335	1997b	0.203	10,970	1997
1996	0.099	0.109	6.864	8.058	9.212	1998b	0.203	10,866	1998
1997	0.097	0.106	7.246	8.667	9.061	1999a	0.203	10,978	1999
1998	0.095	0.103	6.842	8.431	7.818	2000	0.203	10,891	2000
1999	0.089	0.102	6.537	8.141	7.823	2001	0.203	10,784	2001
2000	0.089	0.100	7.938	9.265	11.561	2003	0.203	11,181	2003
2001	0.094	0.102	9.917	11.198	10.681	2003	0.203	11,030	2003
2002	0.092	0.099	7.616	8.995	9.630	2005	0.203	11,008	2005
2003	0.091	0.100	9.238	10.549	11.016	2006a	0.203	10,997	2006
2004	0.091	0.100	10.186	11.615	13.968	2007	0.203	10,952	2007
2005	0.094	0.102	12.104	13.500	17.838	2008	0.203	10,861	2008
2006	0.099	0.109	12.169	14.015	18.888	2009	0.190	10,811	2009
2007	0.098	0.109	11.242	12.983	20.116	2009	0.190	10,853	2009
2008	0.101	0.111	11.599	13.276	24.490	2009	0.190	10,721	2009
2009	0.096	0.107	9.112	10.964	16.046	2009	0.190	10,808	2009
2010	0.087	0.100	9.683	11.450	13.658	2009	0.190	10,850	2009
2015	0.090	0.090	10.056	11.606	22.067	2009	0.190	10,794	2009
2020	0.096	0.113	11.335	12.845	25.355	2009	0.190	10,740	2009
2025	0.098	0.114	11.574	13.090	25.742	2009	0.190	10,559	2009

Notes to Table 4:

1) Carbon coefficients for natural gas and oil are assumed to be constant throughout the period at 14.4 kg C/MBtu for natural gas and 19.75 kg C/MBtu for oil. Carbon emissions factors for electricity are marginal, not average.

2) All prices have been converted to 2008 dollars using implicit GDP deflators from the US Depart. of Commerce, Bureau of Economic Analysis.

3) US DOE refers to US DOE Annual Energy Outlook (AEO) published by the Energy Information Administration. The publication year for the applicable AEO is listed in the table. Full citations are found in Section 7.0.

4) Carbon emission factors (1993-2005) are from the Cadmus Group (1998), carbon emission factors 2010 and 2025 are from US EPA (2007b).

5) Cmcl = commercial; Res = residential

6) Heat rates are average heat rates

Equation 1 summarizes our calculation methodology for estimating ENERGY STAR savings for a single product type in year t:

Equation 1. Energy Star annual energy savings

$$\text{Annual Energy Savings in Year t} = \sum_{n=t-L}^{t} X_n UES_n$$

$$\text{Annual Energy Bill in Year t (Undiscounted)} = AES_t P_t$$

$$\text{Annual Carbon Savings in Year t} = AES_t C_t$$

where;

X_n = The number of Energy Star units sold in year n due to the program

UES_n = The unit energy savings of Energy Star units sold in year n (in kWh or MBtu)

L = product lifetime

AES_t = The aggregate annual energy savings in year t (in kWh or MBtu)

P_t = The energy price in year t (in $/kWh or $/MBtu)

C_t = The carbon emissions factor in year t (in kg/kWh or kg/MBtu)

LBNL has produced an expanded methodology description (Sanchez et al, 2009) which provides a higher level of detail of the energy consumption and savings calculations, as well as detailed descriptions of the assumptions and data sources for each covered product.

ENERGY STAR has implemented over fifty specification revisions for product types included in this analysis. With each specification revision, ENERGY STAR unit sales typically decrease due to the tightened requirements until manufacturers institute product design changes to meet the revised requirements. The initial decline in ENERGY STAR unit sales results in a cohort of units that met the ENERGY STAR criteria under the previous specification but do not meet the revised ENERGY STAR requirements. We calculate the number of these "former" ENERGY STAR units as the difference between ENERGY STAR unit sales in the year preceding a specification change and the actual ENERGY STAR unit sales in subsequent years when the new specification is effective. **Table 6** illustrates a hypothetical application of this methodology. ENERGY STAR realizes savings for the cohort of products until it is completely phased out by products meeting the revised ENERGY STAR criteria. This cohort realizes savings at a UES equivalent to the previous specification.

Table 6. ENERGY STAR market transformation methodology

	2002	2003	2004	2005	2006	2007	2008
ENERGY STAR Sales - Tier 1	300	440	600	340	180	0	0
ENERGY STAR Sales - Tier 2				260	420	600	800
Total ENERGY STAR Sales	300	440	600	600	600	600	800
UES Tier 1 (kWh/yr)	50	50	50	50	50	50	50
UES Tier 2 (kWh/yr)				80	80	80	80
Yearly Energy Saved, 1 Years Sales (kWh/yr)	15,000	22,000	30,000	37,800	42,600	48,000	64,000
Total Yearly Energy Saved (kWh/yr)	15,000	37,000	67,000	104,800	147,400	195,400	259,400

Notes to Table 5:

1) We refer to specification versions as ENERGY STAR Tiers. Tier 1 corresponds to the original and Tier 2 corresponds to the revision.

2) In this example, there were 600 ENERGY STAR units sold in 2004 (the final year of the Tier I specification). In 2005, there were only 340 ENERGY STAR units sold that met the revised Tier II specification. We calculate that 260 units (600-340) were sold in 2005 that continued to meet Tier I levels. We assume that the 260 units accrue savings equivalent to 50 kWh/year (the UES for Tier).

3) This methodology is applied until 2007 when ENERGY STAR units shipped under Tier II is equivalent to ENERGY STAR units shipped under Tier I (in 2004).

We refer to this component of our methodology as a market transformation effect. This methodology assumes that units that met previous ENERGY STAR levels continue to be in compliance with previous levels despite no longer being labeled ENERGY STAR (i.e., manufacturers do not change the design of these previously qualified products to be less efficient). To date, energy consumption test data for non-qualified models submitted by manufacturers to EPA and DOE during a subsequent specification revision support this assumption. In reference to our general program savings equation (Equation 1), when applicable the market transformation effect means that in any given year n, the number of units sold for a single product type that will accrue program savings (X) is equal to:

$$X_n = \sum_{r=1}^{t_n} X_r$$

and the average UES in any given year n, is equal to:

$$UES_n = \sum_{r=1}^{t_n} X_r * UES_r \div X_n$$

where t is the current Tier of the ENERGY STAR specification in year n.

For power system reliability, the electricity savings that matter most are those that occur when the power system is constrained, during periods of peak demand. In most parts of the country, peak demand is driven by high summer cooling loads. ENERGY STAR central air conditioner savings tend to occur on peak, while the auto-off feature of ENERGY STAR copiers tends to save energy off peak. Other products, such as TVs, accrue fairly level savings through peak and off-peak periods.

Peak power reductions are estimated from aggregate energy savings using a conservation load factor (CLF) that relates average load savings to peak load savings for a conservation measure. Conservation load factors were obtained from previous research (when available), developed from time-of-day metered data, or based on assumed time-of-day and seasonal operating patterns (if no metered data were available). A CLF of 1.0 indicates that energy savings are distributed evenly across peak and off-peak periods (e.g., ENERGY STAR TVs). Conservation load factors of less than 1.0 indicate that savings are greater during peak periods (e.g., CLF of central air conditioners), while CLFs of more than 1.0 indicate that savings occur mostly off-peak (e.g., CLF of copier low-power and auto-off modes). Conservation load factor methodology is detailed in Koomey et al. (1990).

4.3 Product Category Overview

Our analysis groups ENERGY STAR product types into the following categories: office equipment, consumer electronics, heating/ventilation/air conditioning (HVAC), lighting, residential appliances, commercial appliances, and other. We summarize our methodology for each product category below.

4.3.1 Office Equipment

Office equipment includes computers, servers, computer monitors, professional displays[4], and imaging equipment.

ENERGY STAR computers incorporate a sleep mode in which a product enters a low power mode after a period of inactivity[5]. The UEC for notebook computers reflects five power consuming modes: charging, active, idle, sleep and off. Servers may qualify as ENERGY STAR by meeting power supply efficiency

[4] The ENERGY STAR specification for "displays" covers computer monitors, digital picture frames, and professional signage. TV's and DPFs are reported with consumer electronics.

[5] Starting in 2009 the requirements for computers will be expressed as total energy consumption, annual kWh based on standardized assumptions regarding operational mode power and weighting for time in mode.

requirements. In addition servers with up to 2 processor sockets must meet an idle power maximum. ENERGY STAR displays must meet maximum power requirements in on, sleep and off mode. ENERGY STAR imaging equipment must meet either a maximum total energy consumption (TEC) requirement expressed as kWh/week or maximum operational mode power requirements (sleep and standby) depending on a product's marking technology and size format[6]. All these products have UECs calculated using the modal approach using with the exception of workstation class computers, and TEC imaging equipment. Workstation class computers have exogenous UECs based on the manufacturer's test data set submitted to EPA. The ENERGY STAR UECs for TEC based imaging equipment are set to the criterion annual kWh rather than calculated based on time in mode.

We model office equipment differently for residential and for commercial settings due to different usage or operating patterns between the two sectors. Commercial operating patterns are derived from equipment audits at various locations that provide time spent in each operating mode, nighttime turn-off rates, and power management success rates (Piette et al. 1995; Nordman et al. 1998; Webber et al. 2001; Lee et al (2000), Roberson et al. 2004). Operating patterns for residential computers are derived from hours-of-use monitoring for a large sample of residential computer users (Media Metrix 2001). Operating patterns for residential displays, MFDs, printers, and scanners are from field measurement data for a sample of California homes (Porter et al. 2006). Low power savings are only realized for ENERGY STAR products that are successfully power managing. Turn-off and enabling rates are taken from Webber et al. (2001) and Roberson et al. (2004).

Office equipment power consumption in operating modes is based on Nordman et al. (1998), Lee (1999), ECOS Consulting (Calwell 2000), LBNL metering (Lee et al. 2000), Roberson et al. (2002), the Star database January 2004 (Webber 2004), and U.S. EPA (2007c). Starting in 2005 the BAU UECs for devices with external power supplies, primarily notebook computers, and inkjet imaging equipment, decline due to the impact of the ENERGY STAR external power supply specification.

Enterprise servers were added as an ENERGY STAR product effective May 2009. Since savings do not accrue to servers until 2009, they do no contribute to the reported achieved. They are included in this report because they contribute to the forecast estimates. The UECs for 1 and 2 socket servers are based on the improvement in idle power consumption. The EPA report to congress (US EPA 2007c), showed servers having low average utilization, so most of the time they are in idle or near idle states, and because published SPEC benchmark data indicated a high (.95 or better) correlation between idle mode and all other load levels (Brown, 2008), so the savings in idle mode are presumed to accrue even at higher load levels. In addition configuration of servers is more individualized than commodity computers making obtaining accurate data on time at load-level, and therefore a full modal accounting, difficult. The UEC for 3 and 4 socket servers is based on the improvement of the power supply efficiency, the operational modes are therefore power supply load levels, the power levels are taken from analysis of the test set submitted to EPA. Servers with 1 or 2 processor sockets are required to ship with processor level power management enabled, but this is not accounted for in the savings estimates as we have insufficient data on either the power management enabling rate for BAU units or rate at which ENERGY STAR units have power management disabled after shipment.

4.3.2 Consumer Electronics

Consumer electronics include audio/video equipment, telephony, set-top boxes, battery charging systems, external power supplies, digital picture frames, TVs, and VCRs.

[6] US EPA defines the on/active mode for displays as the state in which the unit is connected to the power source and producing an image. US EPA defines the idle mode for computers as the state in which the operating system and other software have completed loading, the machine is not asleep and activity is limited to those basic applications that the system starts by default. Standby mode refers to a product's lowest power state.

The ENERGY STAR specification for audio/video products focuses on reducing the power consumption of a device in its standby mode. Savings are assumed to accrue in both active and standby modes since efficiency improvements to achieve standby savings (like remote control and memory) reduce power whether the device is in "on" or "standby" mode. The UECs are calculated using the electronic modal method, except for "audio separates" (amplifiers, receivers, and powered speakers systems) and set-top boxes (STB) all of which have exogenous UECs. Power consumption and usage patterns are derived from Floyd and Webber (1998); Nordman and McMahon (2004); Horowitz et al. (2005); Roth and McKenney (2007); and Porter et al. (2006). The UEC for audio separates is taken from field metering by LBNL.

The UEC for telephony equipment reflects four power-consuming modes: active, charge (empty battery), charge (full battery), and standby. BAU power consumption is measured data taken from Rosen et al. (2001) and measured data by FSEC, LBNL, and UC Berkeley (Webber 2003). The ENERGY STAR standby power consumption is set to the maximum allowable consumption. Savings for charge mode and active mode reflect power reductions due to an improved power supply efficiency that is required by the ENERGY STAR specification. Usage patterns are estimates taken from Rosen et al. (2001).

ENERGY STAR for set-top boxes focuses on reducing the TEC of the product measured in annual kWh. ENERGY STAR for set-top boxes also includes power allowance adders to account for product functionality such as DVRs, extra tuners, and advanced video processing. An exogenous UEC is used, using power consumption and usage patterns developed by Cadmus (Beavers, 2007), based on their analysis of data originally developed by Roth (2007).

ENERGY STAR external power adapters must meet efficiency criteria in both active and no-load modes. ENERGY STAR battery charging system must meet a non-active energy ratio requirement, which is the non-active energy of a battery charging system divided by the energy deliverable by the battery under a known discharge condition. Calwell (2003) provides BAU and ENERGY STAR UECs for external power adapters. BAU and ENERGY STAR UECs for battery charging systems are derived from Webber et al. (2006) the calculation methodology for external power adapters reflects the devices that they are used to power.

ENERGY STAR digital picture frames must meet criteria for maximum power consumption in operational modes and has a standby mode requirement. The UECs are based on the power levels in the manufacture's test set submitted to EPA, the time in mode estimates are LBNL assumptions.

ENERGY STAR televisions originally were required to meet only standby mode criteria. Starting in 2008 ENERGY STAR added criteria for active mode as well, based on the unit's screen size and resolution. ENERGY STAR for digital TV adapters also includes both active and standby eligibility criteria. The UECs for these products are calculated using the electronic modal method. Television power consumption and usage patterns are derived from Rosen et al. (1999); CNET (2005); US EPA (2008b); Horowitz et al. (2005); and Porter et al. (2006). Digital TV adapter power consumption and usage patterns are from Amann (2003) and NYSERDA (2006). The baseline standby power consumption for digital TV adapters is equivalent to the National Telecommunications and Information Administration (NTIA) standard of 2 watts.

4.3.3 HVAC

ENERGY STAR labels both residential and light commercial heating, ventilation and air conditioning (HVAC) equipment. The residential HVAC program covers air-source heat pumps (ASHP), boilers (gas and oil), central air conditioners (CAC), furnaces (gas and oil), geothermal heat pumps, and programmable thermostats. Light commercial HVAC covers central air conditioners and heat pumps with up to 250,000 Btu/hr capacity. Gas/electric package units may also qualify under the light commercial HVAC specification, if they meet the requirements for air conditioners. For heating and cooling equipment, ENERGY STAR eligibility is based solely on efficiency, measured by standard test

procedures such as the average fuel utilization efficiency (AFUE) Heating Seasonal Performance Factor (HSPF), energy efficiency ratio or seasonal energy efficiency ratio (EER, SEER), Integrated Part-Load Value (IPLV) or coefficient of performance (COP). The specification for programmable thermostats has been suspended effective December 31, 2009. Prior to the suspension of the specification, programmable thermostats qualified for the ENERGY STAR label by automating the set back of thermostats at times determined by the building occupant. The UEC calculation method is that of an exogenous UEC. Savings for HVAC products with an applicable minimum federal efficiency standard (ASHP, CAC, furnaces, and boilers) are calculated by modeling improvement of the unit efficiency from the federal minimum level to the ENERGY STAR level, that is, we assume that the efficiency of new units are equal to the standard efficiency. This has the effect of raising the business as usual efficiency and reducing the estimated savings for upgrading to the ENERGY STAR level.

For residential HVAC we derive the baseline UECs using household level data from the 1993 Residential Energy Consumption survey (US DOE 1995a)[7]. We model the baseline UEC using equipment efficiency equal to the federal minimum efficiency standard where applicable. The UECs for ENERGY STAR equipment are similarly modeled but assume ENERGY STAR equipment efficiency levels. Regional UECs are then aggregated to a national average. Our savings estimates do not include improving the quality of equipment installation, appropriately sizing equipment, and/or air sealing within the home. These improvements are a part of the Home Performance with ENERGY STAR program and are accounted for separately by US EPA.

Although the specification for Programmable Thermostats has been suspended they are described here because they contribute to both the current year savings and the cumulative achieved savings. Programmable thermostats are analyzed in conjunction with HVAC equipment to avoid double-counting energy savings between the measures. For simplicity, we assume that HVAC equipment is chosen first and therefore ENERGY STAR HVAC receives its full measure of savings. Programmable thermostat savings are calculated from a forecast of HVAC energy use that takes into account the increasing market penetration of ENERGY STAR HVAC and any changes to the federal minimum efficiency standard.

To account for savings uncertainty related to programmable thermostats, we have made conservative estimates of the number of ENERGY STAR programmable thermostat units that successfully realize savings. The estimate of ENERGY STAR programmable thermostat unit sales is adjusted to account for the following factors:

- Sales represent replacement of manual thermostats only (70% of total ENERGY STAR unit sales)
- EPA is credited with only 40% of ENERGY STAR units that replace manual thermostats
- Only 44% of sales credited to US EPA are installed in homes that did not previously setback the thermostat manually (US DOE, 2004)
- We assume that only 70% of unit sales to homes that did not previously setback manually are properly programmed and successfully achieve energy savings (US DOE, 2004)

Once the four adjustment factors are applied, we credit US EPA savings to less than 10% of total ENERGY STAR programmable thermostat unit sales. We assume a 14% reduction in household heating consumption (RLW 2007)[8]. We do not assume any cooling savings due to the limited data available to

[7] The Residential Energy Consumption Survey (RECS) is a national multistage probability sample survey that the US EIA conducts approximately every 4 years. RECS gathers data primarily by means of personal interviews with householders and a mail survey of the sampled households' energy suppliers. The 1993 RECS sample included more than seven thousand households.

[8] RLW Analytics (2007), which found a household energy savings of approximately 8% per thermostat for homes in New England (RLW 2007). We adjusted the per-household savings by the fraction of household energy consumption due to heating for New England (58%) and arrive at a 14% reduction in heating consumption. The RLW study quantified savings only for furnaces so we do not ascribe any savings to programmable thermostats for A/C.

support verified savings. Beginning in 2011, we assume no additional sales of ENERGY STAR units because ENERGY STAR discontinued the programmable thermostat specification.

While ENERGY STAR New Homes are not covered in this analysis, the effects of ENERGY STAR New Homes are taken into account when estimating savings for ENERGY STAR HVAC equipment. Since ENERGY STAR HVAC equipment is typically part of an ENERGY STAR New Home and counted toward its savings, sales of ENERGY STAR HVAC equipment are first allocated to the New Homes program and the remaining ENERGY STAR equipment sales are accounted for in this analysis.

The UECs for light commercial HVAC products are taken from an LBNL analysis of the EIA Commercial Building Energy Consumption Survey (CBECS). The BAU UEC is based on the amount of conditioned floor area, and the distribution of product types among the CBECS building types and the annual average new energy use for the equipment type. The ENERGY STAR UEC is based on the percent of improvement between the stock average and the ENERGY STAR criterion. The energy use and saving by light commercial HVAC units is expressed in kWh/sqft/year. In 2010 a new federal standard which mandates energy efficiency levels equal to ENERGY STAR, therefore the BAU UEC is set equal to ENERGY STAR and no further savings accrue to the program.

4.3.4 Lighting

Lighting includes residential fixtures (indoor and outdoor), exit signs, traffic signals, compact fluorescent lamps (CFL), and decorative light strands. Lighting equipment is treated using the duty cycle methodology. The specification for traffic signals was suspended in 2007 and the specification for exit signs in 2008 because federal standards were set equal to the ENERGY STAR criteria.

Savings for residential indoor fixtures are based on KEMA (2005), which reports power savings from incandescent/CFL lamp replacement for a sample of monitored fixtures in California homes. We assume replacement of a 65 W incandescent lamp with a 16 W compact fluorescent lamp and a daily operating time of three hours (KEMA, 2005; Vine, 2006). Since ENERGY STAR fixtures require pin-based lamps, we assume savings accrue over the lifetime of the fixture (20 years). Savings for outdoor fixtures assume replacing the equivalent of 109 W incandescent lamp, the average of the Tacoma Public Utility dataset (TPU 1996), with a 36 W fluorescent lamp (Vorsatz et al. 1997). We assume a daily operating time of five hours (Vine et al. 2006).

Through 2005, savings for exit signs are calculated from a BAU UEC that is a market share weighted average across incandescent, CFL, and non-ENERGY STAR LED energy consumption (Suozzo and Nadel, 1998, Updyke 2003). From 2006 onward, the BAU UEC is set equivalent to the federal minimum efficiency standard, which is an average power of five Watts (W) and an annual operating time of 8,760 hours.

Savings for ENERGY STAR traffic signals are based on stock replacement rather than ENERGY STAR unit sales since retrofits are the primary market driver. Red and green traffic signals are modeled separately due to differences in cost effectiveness. Yellow (amber) signals are not analyzed because of their very short operating times. Suozzo (1998) and Caltrans (1999) provide UECs for each signal type analyzed.

Savings for compact fluorescent lamps are consistent with assumptions for residential light fixtures. We assume replacement of a 65 W incandescent lamp with a 16 W compact fluorescent lamp and a daily operating time of three hours (KEMA, 2005; Vine et al. 2005). We assume a lamp lifetime of 6,000 hours, which at 3 hours per day usage equates to five years.

Decorative light strands include mini lamps (100 lamps per strand) and regular lamps (25 lamps per strand). Our baseline for mini strands is 0.42 W/lamp and 5 W/lamp for regular strands. ENERGY

STAR power levels are set equal to minimum program requirements (0.2 W/lamp). The UEC is calculated using an operating time of 10 hours per day and 45 days per year. Power and usage data are from Navigant Consulting (2005).

4.3.5 Residential Appliances

Residential appliances include dehumidifiers, room air cleaners, ceiling fans, ventilation fans, dishwashers, clothes washers, refrigerators, and room air conditioners.

ENERGY STAR dehumidifiers must meet energy performance requirements specified in terms of kWh of energy used per liter of water removed from the air. The UECs are based on the duty cycle. Through 2007, the BAU UEC is derived from energy consumption test data collected by the Canadian Standards Association (CSA) in conjunction with Natural Resources Canada (McWhinney et al. 2005). From 2008 onward, the BAU UEC is equivalent to the applicable federal minimum efficiency standard. The ENERGY STAR UEC represents the minimum efficiency program requirements for an average equipment capacity. We assume annual operating time of 1,620 hours (Cadmus Group 1999).

ENERGY STAR room air cleaners must meet energy performance requirements that are specified in terms of volume of air cleaned per minute (defined as clean air delivery rate or CADR) per W. The UECs are based on the duty cycle. We analyze the following CADR bins (m3/min): 1.4-2.8, 2.8-4.2, 4.2- 5.7, 5.7-7.1, greater than 7.1. BAU wattage is derived from manufacturer power consumption test data for individual product models. ENERGY STAR wattages are extrapolated by dividing the average CADR per CADR bin by the ENERGY STAR efficiency criteria (2 CADR per watt). Our estimate of savings assumes that room air cleaners are operated continuously.

Ceiling and ventilation fans can qualify as ENERGY STAR by meeting efficiency requirements expressed as cubic feet per minute per watt. For both ceiling and ventilation fans the UECs are exogenous. Ceiling fans include fan-only units, fans with lights, and light kit only. We separately model fans located in the southern region versus fans located elsewhere in the US due to the different operating times as summarized below (52% of installed stock in the south and 48% of installed stock elsewhere (US DOE 2004)). Ceiling fan UEC data are taken from Calwell and Horowitz (2001) and are based on a BAU 34 W fan with 180 W of incandescent lighting. Beginning in 2007, our BAU lighting consumption is reduced to 60 W to account for the federal mandate that ceiling fans with integral lights or ceiling fan light kits are required to be shipped with CFL lamps enclosed. The ENERGY STAR case assumes a 31 W fan with 60 W of lighting. We assume a daily operating time for the fan of 9 hours in the south and three hours elsewhere. We assume the lighting is operated three hours per day. ENERGY STAR ventilation fans include range hood fans and bathroom and utility room fans. The reference case UEC is from LBNL analysis (Roberson 2001). In the UEC calculation, usage is modeled as 1 hour a day, 350 days per year. The airflow and efficiency varies between the two airflow capacity types. The reference case UECs for exhaust fan and range hood lighting are from the Tacoma Public Utility dataset (TPU 1996), and are averages. The ENERGY STAR UECs are calculated from the reference cases, assuming a 67% improvement in lighting efficiency.

Refrigerators, freezers, clothes washers, dishwashers, and room air conditioners (RAC) are all subject to federal minimum efficiency standards. The ENERGY STAR program is intended to expand the market for products that significantly exceed the minimum standard. To obtain energy use for these appliances, we first calculated unit energy consumption for units just meeting the federal minimum efficiency standards. The average energy consumption for refrigerators and RACs (under both existing and new efficiency standards) were weighted according to the distribution of products by product class and capacity (Wenzel et al. 1997, US DOE 1995b, US DOE 1997a). In the case of dishwashers and clothes washers a prototypical model was used to calculate energy consumption. Where ENERGY STAR criteria were specified in terms of percent efficiency improvement over standards, the appropriate percentages were then applied to obtain ENERGY STAR energy consumption.

A large share of the energy consumption by clothes washers and dishwashers is due to the use of household hot water, which may be heated using gas, oil, LPG or electricity. (Because oil and LPG water heaters represent only a small fraction of water heaters, they were treated together with gas water heaters for this analysis). The test procedures for these products include the electricity used by the device itself (motor, controls, etc.) and the energy (fuel or electric) used for water heating. The test procedure for clothes washers also includes dryer energy, since remaining moisture content in the load at the end of a wash cycle varies by washer and affects the amount of energy required to dry the load[9]. Dryers may also be gas or electric. We therefore analyzed dishwasher energy savings in three parts: machine energy, which accrued to all devices, electric water heating energy, which accrued to devices installed in electric water heating homes, and gas water heating energy, which accrued to devices installed in gas water heating homes (oil and LPG water heating homes were also included here). Similarly, clothes washer savings are analyzed in five parts: machine, electric water heating, gas water heating, electric drying and gas drying. The shares of water heating by fuel type were taken from US DOE (1999b). Unit energy consumption and savings for clothes washers and dishwashers included machine energy and weighted-average water heating energy for all fuels, expressed as primary energy.

4.3.6 Commercial Appliances

Commercial appliances include commercial refrigeration applications: bottled water coolers, refrigerated beverage vending machines, icemakers, refrigerators and freezers; commercial cooking: fryers, hot food holding cabinets, steamers, ovens, and griddles; and commercial dishwashers. The UEC calculation methodology is duty cycle except for water coolers, refrigerators and freezers, which have exogenous UECs.

ENERGY STAR bottled water coolers include hot and cold units and cold only units. ENERGY STAR focuses on reducing a unit's standby energy consumption and specification requirements are expressed as a maximum standby energy consumption requirement per day. Our BAU and ENERGY STAR UECs are taken from engineering testing conducted by the Cadmus Group, Inc (2000b).

Refrigerated beverage vending machines include both newly manufactured and refurbished units. Units are modeled by the following can capacities: less than 500, 500-600, 600-700, and greater than 800. Baseline UECs are taken from product energy consumption test data gathered by Horowitz (2002). ENERGY STAR UECs are calculated as the required percentage reduction in energy consumption from the current Canadian minimum efficiency standard. UECs also include a standby consumption and an enabling rate for ENERGY STAR units that enter a low power mode after a period of inactivity.

Commercial ice machines include self-contained units, ice maker heads, and remote condenser units. Each product category is divided into low capacity units and high capacity units as denoted by the ENERGY STAR specification. Power consumption test data is from ARI and usage patterns assume that machines are operated 75% of the time (273 days/yr).

Data for commercial refrigerators and freezers are taken from FSTC (2007, 2008). Although the program covers refrigerators, freezers, and ice cream freezers, we model only solid door refrigerators and freezers due to insufficient data regarding ice cream freezers. Efficiencies are expressed as kWh per day.

The specifications for fryers, steamers, oven and griddles include a cooking efficiency (the quantity of energy input into the food expressed as a percent of the energy input to the appliance) and an idle rate, expressed in Btu/hr (gas appliances) or watts (electric). Hot food holding cabinets have only an idle

[9] The Department of Energy changed the test procedure for clothes washers several years ago. Through 2003 the standard was based on energy factors which measure energy per wash cycle for machine and water heating energy. The 2004 and 2007 standards are based on modified energy factors (MEF), which include dryer energy. The current ENERGY STAR specification is expressed in terms of MEF.

energy rate requirement, expressed in watts per cubic foot. UECs for commercial cooking equipment are obtained from the Food Service Technology Center (FSTC 2007, 2009).

Commercial dishwashers include under-the-counter, door, single tank conveyor, and multi-tank conveyor. Each product category is divided into low temperature and high temperature units. ENERGY STAR criteria include a water-per-cycle requirement as well as an idle energy rate requirement. Relevant water consumption, idle energy, and duty cycles are from FSTC (2008).

4.3.7 Other Products

Other ENERGY STAR products include transformers (commercial/industrial and utility) and roofing (residential and commercial). Transformers have UECs calculated from a duty cycle, the UECs for roofing are of the exogenous type. Commercial/industrial transformers assume a BAU UEC for a unit with a 45 kVA rating, a load factor of 35% and a 97.3% efficiency (Suozzo and Nadel, 1998). ENERGY STAR requires an efficiency of 98% based on the specification average of single phase and three phase transformers. Utility transformers assume a BAU UEC for a unit with a 25 kVA rating, a load factor of 30%, and an efficiency of 98.5%. ENERGY STAR requires an efficiency of 98.65% (ORNL 1996).

The ENERGY STAR specification for transformers was suspended in 2007 due the institution of a federal minimum efficiency standard. Transformers are included here because they contribute to the cumulative achieved savings. We do not assume any additional savings from new product shipments throughout the forecast period.

ENERGY STAR roofing has a higher reflectivity than standard roofing in order to reduce heat gains into the building and the resulting cooling load. UES for ENERGY STAR roofing are based on a US average derived from a study of 11 metropolitan areas including: Atlanta, Dallas, Chicago, Houston, Los Angeles, Miami, New Orleans, New York, Philadelphia, Phoenix, and Washington DC. Savings are expressed in primary energy and include cooling savings and increased energy use during the heating season (Konopacki et al. 1997).

5. Results

5.1 Savings for ENERGY STAR labeled products

Table 7 presents the estimated savings of energy, energy bills, carbon emissions and peak load along with the conservation load factor for each included product for the year 2008. In 2008, ENERGY STAR labeled products saved 1.7 Quadrillion Btu (Quads) of primary energy, $17 billion in energy bills, and avoided 40 million metric tons carbon equivalent (MtC eq.) through its voluntary program efforts. For reference, these carbon savings represent 4.0% of residential and commercial building sector carbon emissions in 2008 (US DOE 2008). ENERGY STAR also saved 28 GW of peak power. The following are the top five ENERGY STAR products in terms of carbon savings achieved in 2008:

- CFLs: 8.4 MtC (28% of total)
- Displays: 6.5 MtC (18% of total)
- Printers: 1.9 MtC (6% of total)
- Residential Light Fixtures: 1.7 MtC (5% of total)
- Televisions 1.5 MtC (5% of total)

These five products accounted for over 55% of ENERGY STAR product labeling savings. Projected savings for 2009 and 2010 are shown in Table 8 and Table 9 respectively. We project that carbon savings will increase to 35 MtC in 2008 and 38 MtC in 2009.

Table 7. Achieved Annual Savings in 2008

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2008	MtC		GW
Office Equipment	Computers	48	455	0.85	1.1	0.46
	Servers	0	0	0	-	0
	Displays	305	2800	5.4	1.4	2.7
	Fax	6.6	64	0.12	1.4	3
	Copier	27	250	0.49	3.3	3.2
	Multifunction Device	23	210	0.41	1.1	3.1
	Scanner	2	19	0.036	1	3.5
	Printer	104	968	1.9	3.2	3.5
	Professional Displays	0	0	0	-	0
	Subtotal	516	4760	9.1	1.5	3.9
Consumer Electronics	Digital Picture Frames	0	0	0	33	0
	TVs	84	837	1.5	1	0.9
	VCRs	6.2	61	0.11	1	0.066
	TV/VCR/DVD	16	156	0.28	1	0.17
	DVD Player	14	140	0.25	1	0.15
	Audio Equipment	12	124	0.22	1	0.13
	Telephony	19	190	0.34	1	0.2
	Digital TV Adapter	5.2	54	0.092	0.69	0.081
	Set-top Box	0.018	0.18	0	1	0
	External Power Supplies	49	469	0.87	1	0.52
	Battery Charging Systems	0.83	8.3	0.015	1	0.009
	Subtotal	207	2040	3.7	0.99	2.2
Heating & Cooling	Furnace (Gas or Oil)	60	736	0.9	-	-
	Central Air Conditioner	34	334	0.6	0.15	2.4
	Air-Source Heat Pump	28	279	0.5	0.15	0.72
	Geothermal Heat Pump	9.9	98	0.17	0.15	0.081
	Boiler (Gas or Oil)	5.4	94	0.09	-	-
	Programmable Thermostat	31	403	0.49	0.15	0
	Unitary HVAC	43	391	0.76	0.15	3.1
	Subtotal	211	2340	3.5	0.18	6.2
Residential and Commercial Lighting	Fixtures	98	974	1.7	1	1
	CFLs	475	4720	8.4	1	4.9
	Exit Sign	4.6	42	0.082	1	0.049
	Decorative Light Strands	0	0	0	1	0
	Traffic Signal	9.8	89	0.17	1	0.1
	Subtotal	587	5830	10	1	6.1
Residential Appliances	Room Air Conditioners	20	204	0.36	0.15	1.5
	Dehumidifiers	6.8	68	0.12	0.49	0.15
	Air Cleaners	4.8	47	0.084	1	0.051
	Exhaust Fans	1.5	15	0.027	1	0.016
	Ceiling Fans	1.4	14	0.025	1	0.011
	Dishwashers	38	404	0.63	0.77	0.37
	Refrigerators	22	219	0.39	0.95	0.25
	Clothes Washers	43	459	0.72	0.66	0.52
	Subtotal	138	1430	2.4	0.44	2.8
Commercial Appliances	Water Coolers	12	105	0.21	0.7	0.19
	Commercial Refrigeration	7.1	65	0.13	0.95	0.079
	Hot Food Holding Cabinets	3.2	29	0.056	0.95	0.035
	Fryers	0.12	1.1	0.002	0.95	0.001
	Steamers	0	0	0	0.95	0
	Ice Machines	0.56	5.1	0.01	0.95	0.006
	Dishwashers	1.9	19	0.031	0.95	0.012
	Vending Machines	2.7	25	0.049	0.95	0.031
	Griddles	0	0	0	0.95	0
	Ovens	0	0	0	0.95	0
	Subtotal	27	249	0.48	0.77	0.35
Other	Utility Transformers	0.062	0.56	0.001	1	0.001
	C&I Transformers	0.97	8.8	0.017	0.77	0.013
	Residential Roofing	1.7	15	0.032	0.15	0.22
	Commercial Roofing	41	358	0.76	0.15	4.3
	Subtotal	44	382	0.82	0.15	4.5
TOTAL		1730	17000	30	0.65	28

Notes to Table 7,8.9:
1) Columns may not total due to rounding.
2) Electricity is converted to primary energy using electricity heat rates as shown in Table 3.
3) Energy bills are calculated using yearly U.S. average energy prices. See Table 3.
4) Carbon emissions for electricity are from US EPA (2007). See Table 3.
5) CLFs for clothes washers and dishwashers are derived from PG&E and SCE summer load shape from Ruderman et al. (1989, Table D-1 to D-5 and D-7 to D-11, p. D-1 to D-12). Dehumidifier CLF is based on usage patterns from AD Little (1998). Water cooler CLF is derived from metered load data from Rovi (2001). CLFs for cooling technologies and refrigeration equipment are taken from Koomey et al. (1990). Roofs are assumed to have the same CLF as cooling technologies. Commercial cooking equipment is assumed to have the same CLF as commercial refrigeration. Residential lighting CLFs are based on load profiles taken from an October 1979 report by the CEC. CLFs for exit signs and traffic signals equal one because they operate 24 hours a day. CLFs for consumer electronics equal one because savings are assumed to accrue whether the device is on or off. Office equipment CLFs are derived from assumed operating patterns (Piette et al. 1995, Nordman et al. 1998, and recent printer and scanner metered data). Ceiling fans are assumed to have the same CLF as residential lighting. Exhaust fans encompass several products. The CLF represents a weighted average of intermittent fans (assumed the same as lighting), continuously operated fans (CLF of 1), and rangehood fans (assumed the same as cooking equipment, Ruderman et al., 1989).

Table 8. Expected Annual Savings in 2009

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2008	MtC		GW
Office Equipment	Computers	50	431	0.88	1.1	0.47
	Servers	3.4	28	0.06	0	0.036
	Displays	318	2650	5.6	1.4	2.8
	Fax	6.5	58	0.11	1.4	3.1
	Copier	22	180	0.38	3.3	3.3
	Multifunction Device	32	266	0.56	1.1	3.2
	Scanner	1.5	13	0.027	1.1	3.6
	Printer	106	894	1.9	3.2	3.6
	Professional Displays	0	0	0	0	0
	Subtotal	540	4520	9.5	1.5	4.1
Consumer Electronics	Digital Picture Frames	0	0	0	33	0
	TVs	106	970	1.9	1	1.1
	VCRs	4.8	44	0.084	1	0.05
	TV/VCR/DVD	15	134	0.26	1	0.15
	DVD Player	14	126	0.24	1	0.14
	Audio Equipment	13	117	0.22	1	0.14
	Telephony	21	195	0.37	1	0.22
	Digital TV Adapters	9.2	84	0.16	0.69	0.14
	Set-top Box	4.5	41	0.079	1	0.048
	External Power Supplies	50	432	0.87	1	0.52
	Battery Charging Systems	1.3	12	0.022	1	0.013
	Subtotal	237	2150	4.2	0.98	2.6
Heating & Cooling	Furnace (Gas or Oil)	65	651	0.98	-	-
	Central Air Conditioner	37	336	0.64	0.15	2.6
	Air-Source Heat Pump	31	287	0.55	0.15	0.81
	Geothermal Heat Pump	12	114	0.22	0.15	0.1
	Boiler (Gas or Oil)	6.1	73	0.1	-	-
	Programmable Thermostat	33	344	0.53	0.15	0
	Unitary HVAC	51	420	0.9	0.15	3.6
	Subtotal	236	2230	3.9	0.18	7.1
Res and Com Lighting	Fixtures	125	1150	2.2	1	1.3
	CFLs	591	5420	10	1	6.1
	Exit Sign	4.1	34	0.072	1	0.043
	Decorative Light Strand	0	0	0	1	0
	Traffic Signal	9.8	81	0.17	1	0.1
	Subtotal	730	6690	13	1	7.5
Residential Appliances	Room Air Conditioners	24	218	0.42	0.15	1.7
	Dehumidifiers	8.9	82	0.16	0.49	0.19
	Air Cleaners	6.5	59	0.11	1	0.068
	Exhaust Fans	1.8	16	0.031	1	0.018
	Ceiling Fans	1.5	14	0.027	1	0.012
	Dishwashers	44	419	0.74	0.77	0.44
	Refrigerators	26	234	0.45	0.95	0.28
	Clothes Washers	46	430	0.77	0.65	0.55
	Subtotal	158	1470	2.7	0.44	3.2
Commercial Appliances	Water Coolers	14	113	0.24	0.7	0.22
	Commercial Refrigeration	9.7	80	0.17	0.95	0.11
	Hot Food Holding Cabinets	4.3	35	0.075	0.95	0.047
	Fryers	0.16	1.3	0.003	0.95	0.002
	Steamers	0	0	0	0.95	0
	Ice Machines	1.1	9.4	0.02	0.95	0.013
	Dishwashers	3.8	32	0.062	0.95	0.025
	Vending Machines	4.1	34	0.072	0.95	0.045
	Griddles	0.008	0.066	0	0.95	0
	Ovens	0.22	1.8	0.003	0.95	0
	Subtotal	37	306	0.65	0.77	0.46
Other	Utility Transformers	0.062	0.51	0.001	1	0.001
	C&I Transformers	0.97	8	0.017	0.77	0.013
	Residential Roofing	2.1	19	0.041	0.15	0.28
	Commercial Roofing	39	322	0.72	0.15	4
	Subtotal	42	349	0.78	0.15	4.3
TOTAL		1980	17700	35	0.66	31

Table 9. Expected Annual Savings in 2010

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2008	MtC		GW
Office Equipment	Computers	53	401	0.93	1.1	0.49
	Servers	6.7	48	0.12	0	0.071
	Displays	315	2270	5.5	1.5	2.7
	Fax	6.7	53	0.12	1.4	3
	Copier	16	115	0.28	3.3	3.3
	Multifunction Device	42	303	0.74	1.1	3.2
	Scanner	1	8	0.018	1.1	3.6
	Printer	104	757	1.8	3.2	3.6
	Professional Displays	0.001	0.008	0	0.44	0.027
	Subtotal	545	3960	9.5	1.5	4.2
Consumer Electronics	Digital Picture Frames	0	0	0	24	0
	TVs	128	1050	2.2	1	1.3
	VCRs	1.9	16	0.034	1	0.02
	TV/VCR/DVD	14	114	0.24	1	0.15
	DVD Player	13	108	0.23	1	0.14
	Audio Equipment	13	106	0.23	1	0.14
	Telephony	23	188	0.4	1	0.24
	Digital TV Adapters	9.2	76	0.16	0.69	0.14
	Set-top Box	9	74	0.16	1	0.095
	External Power Supplies	48	368	0.84	1	0.51
	Battery Charging Systems	1.6	13	0.028	1	0.017
	Subtotal	261	2110	4.6	0.98	2.8
Heating & Cooling	Furnace (Gas or Oil)	71	692	1.1	-	-
	Central Air Conditioner	39	322	0.69	0.15	2.8
	Air-Source Heat Pump	34	278	0.59	0.15	0.88
	Geothermal Heat Pump	15	123	0.26	0.15	0.12
	Boiler (Gas or Oil)	6.9	75	0.11	-	-
	Programmable Thermostat	36	349	0.57	0.15	0
	Unitary HVAC	51	363	0.9	0.15	3.6
	Subtotal	253	2200	4.2	0.18	7.4
Res and Com Lighting	Fixtures	158	1290	2.8	1	1.6
	CFLs	702	5750	12	1	7.2
	Exit Sign	3.4	24	0.06	1	0.036
	Decorative Light Strand	0	0	0	1	0
	Traffic Signal	9	64	0.16	1	0.095
	Subtotal	873	7130	15	1	9
Residential Appliances	Room Air Conditioners	27	220	0.47	0.15	1.9
	Dehumidifiers	11	90	0.19	0.5	0.23
	Air Cleaners	8.3	68	0.15	1	0.087
	Exhaust Fans	2	17	0.036	1	0.021
	Ceiling Fans	1.6	13	0.028	1	0.013
	Dishwashers	46	399	0.76	0.77	0.45
	Refrigerators	29	239	0.51	0.95	0.32
	Clothes Washers	48	418	0.81	0.65	0.59
	Subtotal	173	1460	3	0.43	3.6
Commercial Appliances	Water Coolers	16	114	0.28	0.7	0.25
	Commercial Refrigeration	10	73	0.18	0.95	0.11
	Hot Food Holding Cabinets	5.4	38	0.094	0.95	0.059
	Fryers	0.19	1.4	0.003	0.95	0.002
	Steamers	0	0	0	0.95	0
	Ice Machines	1.7	12	0.031	0.95	0.019
	Dishwashers	5.8	45	0.094	0.95	0.038
	Vending Machines	5.5	39	0.096	0.95	0.06
	-Griddles	0.029	0.24	0	0.95	0
	Ovens	0.67	5.5	0.01	0.95	0.002
	Subtotal	46	328	0.79	0.76	0.55
Other	Utility Transformers	0.063	0.44	0.001	1	0.001
	C&I Transformers	0.98	6.9	0.017	0.77	0.013
	Residential Roofing	2.6	19	0.049	0.15	0.35
	Commercial Roofing	44	299	0.8	0.15	4.5
	Subtotal	48	325	0.87	0.15	4.9
TOTAL		2200	17500	38	0.66	34

Estimates of cumulative savings 1993-2008 and 2009-2015 are summarized in Table 10. Through 2008, ENERGY STAR labeled products saved 8.8 Quads of primary energy, $83 billion dollars in energy bills, and avoided 156 MtC. Although ENERGY STAR labeled products encompass over forty product types, only five of those product types accounted for 55% of all ENERGY STAR carbon reductions achieved to date. Those product types are as follows (ranked by total carbon avoided through 2008):

- Displays: 38.4 MtC (24% of total)
- CFLs: 28 MtC (17% of total)
- Printers: 14 MtC (8% of total)
- Residential light fixtures: 7.1 MtC (4% of total)
- TVs: 6.4 MtC (4% of total)

Over the period 2009 to 2015, ENERGY STAR labeled products are projected to save 18.1 Quads of primary energy, $139 billion dollars in energy bills (4% discount rate), and avoid 316 MtC. For reference, these carbon savings represent 6.4% of the projected U.S. carbon emissions for the residential and commercial building sectors over this period (US DOE 2008). The following five product types account for 65% of future carbon avoided:

- CFLs: 105 MtC (33% of total)
- Displays: 38 MtC (12% of total)
- Residential light fixtures: 30 MtC (9% of total)
- Televisions: 19 MtC (6% of total)
- Printers: 12 MtC (4% of total)

Table 10. Cumulative ENERGY STAR Savings (1993-2015)

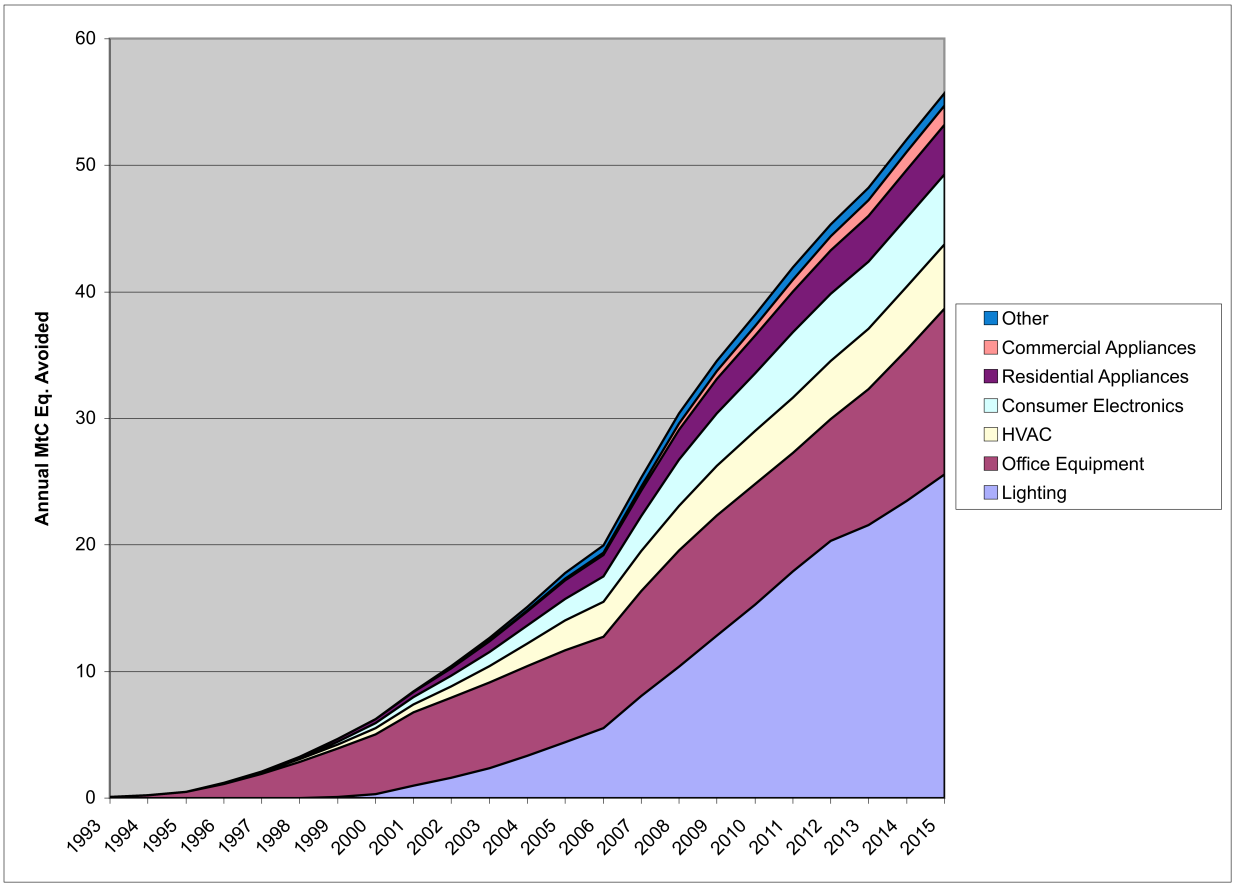
Savings Analysis Period		Achieved Savings (through 2008)			Projected Savings (2009-2015)		
Program	**Product**	**Primary Energy Savings**	**Disc Energy Bill Savings**	**Carbon Avoided**	**Primary Energy Savings**	**Disc Energy Bill Savings**	**Carbon Avoided**
		Trillion Btu	Million $2008	MtC	Trillion Btu	Million $2008	MtC
Office Equipment	Computers	266	$2,420	4.8	637	$4,450	11
	Servers	0	$0	0	152	$979	2.7
	Displays	2,440	$21,300	44	2,160	$15,000	38
	Fax	106	$965	1.9	56	$427	0.98
	Copier	199	$1,730	3.6	63	$464	1.1
	Multifunction Device	188	$1,620	3.4	401	$2,720	7
	Scanner	43	$377	0.78	5	$42	0.095
	Printer	776	$6,880	14	682	$4,840	12
	Professional Display	0	$0	0	56	$355	0.98
	Subtotal	4,020	$35,300	73	4,210	$29,300	74
Consumer Electronics	TVs	354	$3,420	6.4	1,090	$8,660	19
	VCRs	99	$933	1.8	8	$69	0.14
	TV/VCR/DVD	99	$951	1.8	79	$640	1.4
	DVD Player	69	$671	1.3	102	$811	1.8
	Audio Equipment	69	$661	1.2	84	$678	1.5
	Telephony	52	$514	0.93	174	$1,390	3.1
	Digital TV Adapters	5	$58	0.092	32	$268	0.55
	Set-top Box	0	$1	0.0017	195	$1,500	3.4
	External Power Supplies	73	$698	1.3	233	$1,790	4.1
	Battery Charging Systems	1	$13	0.022	16	$124	0.28
	Subtotal	822	$7,920	15	2,020	$15,900	35
Heating & Cooling	Furnace (Gas or Oil)	346	$4,040	5.3	568	$5,190	8.6
	Central Air Conditioner	173	$1,670	3.1	310	$2,470	5.4
	Air-Source Heat Pump	130	$1,270	2.3	275	$2,180	4.8
	Geothermal Heat Pump	26	$257	0.46	146	$1,150	2.6
	Boiler (Gas or Oil)	25	$377	0.42	58	$650	0.94
	Programmable Thermostat	219	$2,500	3.5	210	$2,030	3.3
	Light commercial HVAC	138	$1,230	2.5	358	$2,450	6.3
	Subtotal	1,060	$11,300	18	1,930	$16,100	32
Lighting	Fixtures	396	$3,840	7.1	1,730	$13,600	30
	CFLs	1,580	$15,400	28	5,990	$47,400	105
	Exit Sign	37	$323	0.68	14	$103	0.25
	Decorative Light Strands	0	$0	0	36	$273	0.64
	Traffic Signal	59	$515	1.1	40	$287	0.7
	Subtotal	2,070	$20,100	37	7,820	$61,700	137
Residential Appliances	Room Air Conditioners	96	$924	1.7	227	$1,800	4
	Dehumidifiers	18	$181	0.33	95	$754	1.7
	Air Cleaners	11	$111	0.2	86	$678	1.5
	Exhaust Fans	5	$51	0.092	16	$131	0.29
	Ceiling Fans	6	$57	0.1	11	$89	0.19
	Dishwashers	145	$1,530	2.5	336	$2,820	5.6
	Refrigerators	126	$1,210	2.3	257	$2,030	4.5
	Clothes washers	239	$2,480	4.1	350	$2,920	5.9
	Subtotal	647	$6,540	11	1,380	$11,200	24
Commercial Appliances	Water Coolers	40	$353	0.71	138	$927	2.4
	Commercial Refrigeration	17	$152	0.3	85	$577	1.5
	Hot Food Holding Cabinets	7	$67	0.13	52	$349	0.92
	Fryers	0	$3	0.0061	2	$12	0.032
	Steamers	0	$0	0.0000	0	$2	0.0048
	Vending Machines	5	$47	0.093	59	$394	1
	Griddles	0	$0	0	1	$8	0.019
	Ovens	0	$0	0	18	$132	0.28
	Subtotal	72	$646	1.3	426	$2,890	7.4
Other	Utility Transformers	1	$5	0.011	0	$3	0.0077
	C&I Transformers	5	$43	0.088	7	$47	0.12
	Residential Roofing	5	$39	0.088	25	$183	0.48
	Commercial Roofing	160	$1,340	3	323	$2,110	5.9
	Subtotal	6,670	$61,700	120	11,000	$82,500	191
TOTAL		8,860	$83,300	158	18,100	$139,000	316

Notes to Table 10:
1) Columns may not total due to rounding.

2) Electricity is converted to primary energy using a conversion factor listed in Table 3
3) Disc = discounted, energy bills are calculated using yearly U.S. average energy prices (Table 3) and are discounted at 4%
4) Carbon emissions for electricity are listed in Table 2.

Figure 2 shows the allocation of ENERGY STAR labeled product savings across the seven categories. The estimates of achieved annual savings are estimated to increase from less than 0.1 MtC in 1993 to 30.4 MtC in 2008. We project annual savings will increase to 55.7 MtC in 2015. The results show the critical importance of the office equipment and lighting product categories to overall ENERGY STAR product savings. In 2008, ENERGY STAR office equipment and lighting together avoided 19.5 MtC, approximately 65% of the total annual carbon reductions for ENERGY STAR labeled products. We expect carbon reductions for ENERGY STAR office equipment and lighting to grow to 38.67 MtC in 2015, representing 69% of total annual carbon reductions. Maintaining the relevance of the ENERGY STAR brand for office equipment and lighting will likely be a key indicator of program impact in the future.

Figure 2. Estimated Carbon Savings for ENERGY STAR Labeled Products (1993-2015)



5.2 Sensitivity Analysis

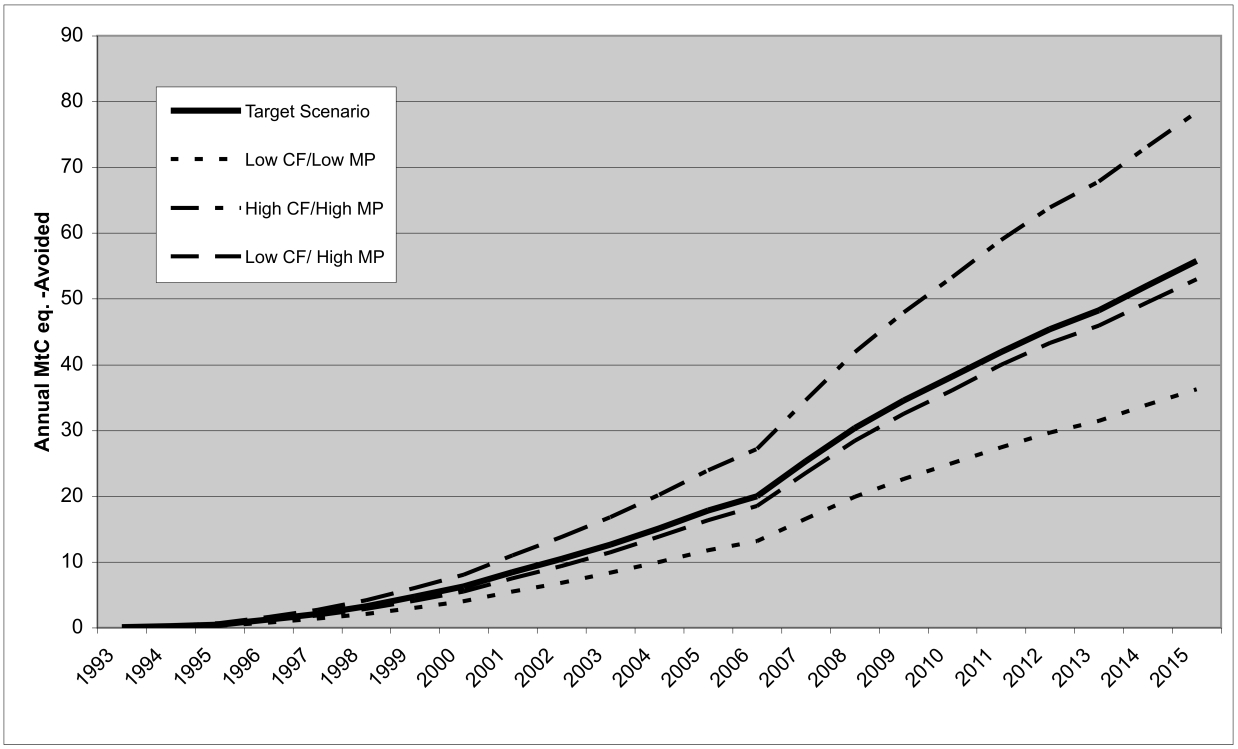
One method of addressing the uncertainty inherent in the model is to bracket the projected "best estimate" savings by varying key inputs that globally affect the model results. We examined the sensitivity of the best-estimate carbon reductions under the following scenarios for the periods 1993 to 2008 and 2009 to 2015:

- The marginal carbon factor for electricity was reduced by 20%, ENERGY STAR sales were reduced by 20% (low CF/low MP)

- The marginal carbon factor for electricity was increased by 20%, ENERGY STAR sales were increased by 20% (high CF/high MP)
- The marginal carbon factor for electricity was reduced by 20% and ENERGY STAR sales were increased by 20% (low CF/high MP)

Figure 3 illustrates the results of this sensitivity analysis. These results bound the best estimate of carbon avoided between 104 MtC and 213 MtC for the period 1993-2008 and between 206 MtC and 444 MtC for the period 2009-2015. The fluctuation in ENERGY STAR unit sales, fuel supply, fuel demand, and fuel mix are highly difficult to predict and model over the twenty-three year analysis period. However, even in a "worst case" scenario, the analysis shows substantial reductions in carbon achieved by ENERGY STAR labeled products.

Figure 3. Sensitivity Analysis of Carbon Savings 1993-2025



6. Limitations to the Analysis

The analysis is based on a bottom-up model for quantifying US EPA ENERGY STAR labeled product savings. General limitations to a bottom-up approach occur in two main areas: 1) the model requires numerous detailed inputs to generate the end result and; 2) uncertainty in those inputs are additive through the process. These limitations mean that collecting and documenting high-quality inputs is essential, which can be a labor-intensive and expensive process. As a result, identifying areas of critical uncertainty and sensitivity and then targeting data collection and verification activities at those areas is key to successful results. We generalize specific limitations to three main areas: forecasting, inputs, and model structure as shown in **Table 11**.

Table 11. Limitation to the Analysis

Forecasting	Inputs	Model Structure
1. Projecting future ENERGY STAR unit sales 2. Projecting key global inputs (energy prices, electricity heat rates, carbon emission factors) 3. Projecting changes in business as usual efficiency 4. Identifying and incorporating emerging or new technologies	1. UECs based on underlying power and usage patterns that can vary within a product type or at the consumer, organization, or regional level 2. UECs represent a national average only 3. Power and usage data often based on a smaller and regionally based sample (particularly in the case of office equipment and consumer electronics) 4. Power and usage change over time and need to be tracked consistently	1. Only includes finalized ENERGY STAR specifications and national energy efficiency standards 2. Attributes all savings to US EPA and does not reconcile ENERGY STAR savings with supporting utility and procurement programs 3. Does not rigorously capture new/emerging technologies and its effect on baseline efficiency and ENERGY STAR savings 4. Model is reactive rather than active, meaning that the model is updated subsequent to a technology market changing

7. Conclusions

Since the program inception in 1992, ENERGY STAR has become a leading international brand for energy efficient products. As such, ENERGY STAR achievements to date and projected savings have a critical impact on the success of both US and international energy efficiency programs. This report summarizes energy, carbon, and monetary impacts from US EPA's ENERGY STAR voluntary product labeling program. Regional, national and international stakeholders can use these results to evaluate energy efficiency opportunities associated with the ENERGY STAR program. US EPA's ENERGY STAR has been successful in reducing carbon emissions through its voluntary product labeling efforts. Through 2008, the program saved 8.8 Quads of primary energy and avoided 158 MtC equivalent. The forecast shows that the program is expected to save 18.1 Quads of primary energy and avoid 316 MtC equivalent over the period 2008-2015. The sensitivity analysis bounds the best estimate of carbon avoided between 104 MtC and 213 MtC (1993 to 2007) and between 206 MtC and 444 MtC (2008 to 2015).

Much of the program's success to date is attributable to ENERGY STAR office equipment and lighting. The analysis demonstrates the continued importance of these product categories toward realizing future ENERGY STAR program goals. Strategies for continued success include maintaining program relevance through tightened specifications, exploring new approaches to improving a product's energy performance including new technologies and market trends, and broadening the portfolio of office equipment products covered by the ENERGY STAR program.

References

Amann, Jennifer Thorne. 2003. Set-top boxes: Opportunities and issues in setting efficiency standards: Report AO41. American Council for an Energy Efficient Economy, Washington, DC.

Beavers, D. 2007. Energy Star Projected Shipments of Set-top Boxes Version 2.0 Specification. (spreadsheet). Waltham, Massachusetts: The Cadmus Group, Inc.

Brown, R., C. Webber, J. Koomey. 2002. "Status and Future Directions of the ENERGY STAR Program." Energy--The International Journal. volume. 27, number. 5. (also published as LBNL-50859; Lawrence Berkeley National Laboratory, Berkeley CA). May. pp. 505-520.

The Cadmus Group, Inc. (Cadmus Group) and Energy Systems Consulting, Inc., 1998. Regional electricity emissions factors: final report. Prepared for the U.S. Environmental Protection Agency, Atmospheric Pollution Prevention Division under contract 68-W6-0050. Washington, DC. November.

Cadmus Group. 1999. Preliminary market background report for residential dehumidifiers. Prepared for the U.S. Environmental Protection Agency, Climate Protection Division under contract 68-W6-0050. Washington, DC. September.

Cadmus (the Cadmus Group, Inc.). 2000a. Preliminary market background report for residential ventilation fans. Prepared for the U.S. Environmental Protection Agency, Climate Protection Division, ENERGY STAR program under contract 68-W6-0050. Washington, DC. June.

Cadmus (the Cadmus Group, Inc.). 2000b. Product testing and analysis of water dispensers. Prepared for the U.S. Environmental Protection Agency, Climate Protection Division, ENERGY STAR program under contract 68-W6-0050. Washington, DC. February.

Cadmus (the Cadmus Group, Inc.). 2007. Personal communication with David Beavers.

Calwell, C. and N. Horowitz. 2001. "Ceiling fans: fulfilling the energy efficiency promise." Home Energy Magazine. January/February. pp 24-29.

Calwell, C. 2003. The European Code of Conduct: How can you lead a global effort to improve power supply efficiency? Presented to the European Commission- Directorate General JRC, Joint Research Center, Institute for Environment and Sustainability, Renewable Energies Unit. Ispra, Italy. April.

Caltrans. 1999. A Caltrans Alternative Traffic Signal Illumination Draft Final Report. Published by the State of California, Department of Transportation.

CNET. 2005. Power consumption results for twenty televisions tested.

Floyd, D. and C. Webber. 1998. Leaking electricity: individual field measurements of consumer electronics. In Proceedings of the 1998 Summer Study on Energy Efficiency in Buildings. Washington DC: American Council for an Energy Efficient Economy. August.

Food Service Technology Center. 2007, 2008, 2009. Life cycle and energy cost calculators for food service equipment. Published by Fisher Nickel, Inc. San Francisco, CA. Data available at http://www.fishnick.com/

Gartner Research. 2001. Special report prepared for the United States Environmental Protection Agency: ENERGY STAR Market Share of computers, monitors, printers, copiers, facsimile, and MFDs. Washington, DC.

Horowitz, Marvin. 2001. "Economic indicators of market transformation: energy efficient lighting and EPA's Green Lights." The Energy Journal: volume 22, number 4. pp. 95-122.

Horowitz, Marvin. 2004. "Electricity intensity in the commercial Sector: market and public program effects." The Energy Journal: volume 25, number 2. pp. 115-137.

Horowitz, Marvin J. 2007. "Changes in electricity demand in the United States from the 1970s to 2003." The Energy Journal: volume 28, number 3.

Horowitz, Noah. 2002. Recommendations for beverage vending machine performance specifications. Prepared for the US Environmental Protection Agency, Climate Protection Division, ENERGY STAR program by the Natural Resources Defense Council. Washington DC. October.

Horowitz, Noah, P. Ostendorp, S. Foster, and C. Calwell. 2005. Televisions – active mode energy use and opportunities for energy savings. Issued by Natural Resources Defense Council (NRDC). San Francisco, CA. March.

ICF Consulting. 2003. Energy Star Market Penetration Report Calendar Year 2002. Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. June.

ICF Consulting. 2004. Energy Star Market Penetration Report Calendar Year 2003. Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. September.

ICF Consulting. 2006a. Energy Star Unit Shipment Data Report Calendar Year 2004. Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. January.

ICF Consulting. 2006b. Energy Star Unit Shipment Data Report Calendar Year 2005 (Final Draft). Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. August.

ICF Consulting. 2007. Energy Star Unit Shipment Data Report Calendar Year 2006 (Final Draft). Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. May.

ICF Consulting. 2008. Energy Star Unit Shipment Data Report Calendar Year 2007 (Final). Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. July.

ICF Consulting. 2009. Energy Star Unit Shipment Data Report Calendar Year 2008. Prepared for the US Environmental Protection Agency, Climate Protection Partnership Division, ENERGY STAR Program. Washington, DC. August

KEMA Inc. 2005. CFL metering study final report. Prepared for Pacific Gas and Electric (San Francisco, CA), San Diego Gas and Electric (San Diego, CA), and Southern California Edison (Rosemead, CA). Oakland, CA. February.

Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek, and L. Gartland. 1997. Cooling energy savings potential of light-colored roofs for residential and commercial buildings in 11 US metropolitan Areas. LBNL-39433. Berkeley, CA. Lawrence Berkeley National Laboratory, May.

Koomey, Jonathan, Arthur H. Rosenfeld, and Ashok K. Gadgil. 1990. "Conservation Screening Curves to Compare Efficiency Investments to Power Plants". Energy Policy 18(8) October: 774–782.

Lee, J. 1999. Energy Star Office Equipment Program. Lawrence Berkeley National Laboratory. Excel workbook. October.

Lee, J., R. Brown, and B. Nordman. 2000. Power Consumption of Commercial Printers, Draft, Lawrence Berkeley National Laboratory. Spreadsheet. February.

McNary, Bill. 2009, 2007 ENERGY STAR Qualified Appliance Retail Sales Data - National – Final. D& R International. July. Excel workbook. Source: http://www.energystar.gov/index.cfm?c=manuf_res.pt_appliances

McWhinney, M., A. Fanara, R. Clark, C. Hershberg, R. Schmeltz, and J. Roberson. 2005. "ENERGY STAR product specification development framework: using data and analysis to make program decisions". Energy Policy 33 (2005) 1613-1625.

Media Metrix. 2001. Hard Scan Volume 1 and Softscan (Third Quarter). Released as electronic data. New, York, New York.

Navigant Consulting. 2006. Decorative Light String Market Assessment Report. Prepared for Natural Resources Canada. September.

Nordman, B., M.A. Piette, B. Pon and K. Kinney, 1998. It's midnight...is your copier on: Energy Star copier performance. LBNL-41332. Berkeley, CA. Lawrence Berkeley National Laboratory, February.

Nordman, B and J. McMahon. 2004. Developing and testing low power mode measurement methods. Prepared for the California Energy Commission Public Interest Research Program (PIER) by Lawrence Berkeley National Laboratory under contract 500-99-013-TA20-5. CEC paper 500-04-057. Berkeley, CA. September.

NYSERDA. 2006. Workbook Documenting Calculations. Appliance Standards and Advisory Committee: Consumer Audio and Video Products – DTAs. June.

Oak Ridge National Laboratory (ORNL). 1996. Determination analysis of energy conservation standards for distribution transformers. ORNL-6847. Oak Ridge National Laboratory, Oak Ridge, TN.

Piette, M.A., M. Cramer, J. Eto and J. Koomey, 1995. Office technology energy use and savings potential in New York. Completed for the New York State Energy Research and Development Authority and Consolidated Edison by Lawrence Berkeley Laboratory. Contract #1955-EEED-BES-93, also published as LBL-36752. Berkeley, CA. January.

Porter, S., L. Moorefield and P. May-Ostendorp. 2006. Final field research report. Prepared for the California Energy Commission Public Interest Research Program (PIER) by Ecos Consulting under contract 500-04-030. Durango, CO. October.

RLW Analytics. 2007. Validating the impact of programmable thermostats: final report. Prepared for GasNetworks by RLW Analytics. Middletown, CT. January.

Roberson, J. A., C. Webber, M. McWhinney, R. Brown, M. Pinckard, Busch, J. 2004. After-hours power status of office equipment and energy use of miscellaneous plug-load equipment. LBNL-53729. Revised. Berkeley, CA. Lawrence Berkeley National Laboratory, May

Roberson, J. 2001. Ventilation fan energy analysis. (Spreadsheet Ventfans1.xls). Lawrence Berkeley National Laboratory.

Rosen, Karen, Alan Meier, and Stephan Zandelin. 2001. Energy Use of Settop Boxes and Telephony Products in the US. LBNL-45305. Lawrence Berkeley National Laboratory. June.

Roth, K. and K. McKenney. 2007. Residential consumer electronics electricity consumption in the United States. Published in the proceedings from the 2007 European Council for an Energy Efficient Economy (ECEEE) Summer Study. La Colle sur Loup, France, June 4-9.

Sanchez, M. C., G. Homan, J. Lai, R. Brown, 2009. Calendar Year 2007 Program Benefits for U.S. EPA Energy Star Labeled Products: Expanded Methodology. Lawrence Berkeley Laboratory. Contract # DE-AC02-05CH11231. Berkeley, CA. September.

Suozzo, M. and S. Nadel. 1998. Selecting targets for market transformation programs: A national analysis. Published by the American Council for an Energy Efficient Economy, Washington, DC. August.

Suozzo, Margaret. 1998. A Market Transformation Opportunity Assessment for LED Traffic Signals. Published by the American Council for an Energy Efficient Economy. Washington, DC. April.

Swope, Tobias. 2009. Email communication. Estimated 2008 market shares for US DOE ENERGY STAR labeled products. D& R International. July.

TPU (Tacoma Public Utility). 1996. Measured Loads of Residential Lighting. Unpublished spreadsheet analysis of indoor and outdoor fixtures.

Updyke, C. 2003. U.S. Shipments of Exit Signs by Technology. Washington D.C.: National Electrical Manufacturers Association.

US DOC, United States Department of Commerce. 2007. Bureau of Economic Analysis, National Economic Accounts. Current dollar and real gross domestic product. January.

US DOE, United States Department of Energy. 1995. Residential energy consumption survey 1993: Housing Characteristics. DOE/EIA-0314(93). Energy Information Administration, Office of Energy Markets and End Use. Washington, DC. June.

US DOE, United States Department of Energy. 1996a. Annual energy outlook 1996 with projections to 2015. DOE/EIA-0383(96). Energy Information Administration. Washington, DC. January.

US DOE, United States Department of Energy. 1996b. Annual energy outlook 1997 with projections to 2015. DOE/EIA-0383(97). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 1997. Annual energy outlook 1998 with projections to 2020. DOE/EIA-0383(98). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 1998. Annual energy outlook 1999 with projections to 2020. DOE/EIA-0383(99). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 1999. Annual energy outlook 2000 with projections to 2020. DOE/EIA-0383(2000). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 2000. Annual energy outlook 2001 with projections to 2020. DOE/EIA-0383(2001). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 2001. Annual energy outlook 2002 with projections to 2020. DOE/EIA-0383(2002). Energy Information Administration. Washington, DC. December.

US DOE, United States Department of Energy. 2003. Annual energy outlook 2003 with projections to 2025. DOE/EIA-0383(2003). Energy Information Administration. Washington, DC. January.

US DOE, United States Department of Energy. 2004. Residential Energy Consumption Survey 2001: Housing Characteristics. DOE/EIA-0314(01). Energy Information Administration, Office of Energy Markets and End Use. Washington, DC.

US DOE, United States Department of Energy. 2005. Annual Energy Outlook 2005 with Projections to 2025. DOE/EIA-0383(2005). Energy Information Administration. Washington, DC. February.

US DOE, United States Department of Energy. 2006. Annual Energy Outlook 2006 with Projections to 2025. DOE/EIA-0383(2006). Energy Information Administration. Washington, DC. February.

US DOE, United States Department of Energy. 2007. Annual Energy Outlook 2007 with Projections to 2030. DOE/EIA-0383(2007). Energy Information Administration. Washington, DC. February.

US DOE, United States Department of Energy. 2008. Annual Energy Outlook 2008 with Projections to 2030. DOE/EIA-0383(2008). Energy Information Administration. Washington, DC. June.

US EPA, United States Environmental Protection Agency. 2008a. Maintaining the value of ENERGY STAR 2007 Report. United States Environmental Protection Agency, Washington, DC.

US EPA, United States Environmental Protection Agency. 2008b. Dataset used to determine Draft Final Version 3.0 Levels. Available online at: http://www.energystar.gov/index.cfm?c=revisions.tv_vcr_spec

US EPA, United States Environmental Protection Agency. 2007a. ENERGY STAR and other climate protection partnerships 2006 annual report. United States Environmental Protection Agency, Washington, DC. October.

US EPA, United States Environmental Protection Agency. 2007b. Estimating Avoided Carbon Emissions from US Environmental Protection Agency, Climate Protection Partnership Programs. Prepared by Ashley King, Environmental Scientist (US EPA). Washington DC. July 26.

US EPA, United States Environmental Protection Agency. 2007c. Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431. August 2.

Vine, E. and D. Fielding. An evaluation of residential CFL hours-of-use methodologies and estimates: Recommendations for evaluators and program managers. Energy and Buildings 38 (2006) 1388-1394.

Vorsatz, D., L. Shown, J. Koomey, M. Moezzi, A. Denver, and B. Atkinson, 1997. Lighting Market Sourcebook for the U.S. LBNL-39102. Berkeley, CA. Lawrence Berkeley National Laboratory, December.

Webber, C., D. Korn, M. Sanchez. 2006. Savings Potential of ENERGY STAR External Power Adapters and Battery Chargers. LBNL-62399. Lawrence Berkeley National Laboratory, Berkeley CA. also published in Proceedings of the 2006 ACEEE Summer Study on Energy Efficiency in Buildings. Asilomar, CA. August. 15 pgs.

Webber, C. 2003. Compilation of FSEC, LBNL, UCB Telephony Field Power Measurements. Lawrence Berkeley National Laboratory.

Webber, C., J. Roberson, R. Brown, C. Payne, B. Nordman, J. Koomey. 2001. Field Surveys of Office Equipment Operating Patterns. LBNL-46930. Berkeley, CA. Lawrence Berkeley National Laboratory, September.

Webber, C., R. Brown, J. Koomey. 2000. "Savings Estimates for the ENERGY STAR® Voluntary Labeling Program." Energy Policy 28(2000)1137-1149.